WSDOT PAVEMENT GUIDE

Volume 3

Pavement Analysis Computer Software and Case Studies

For Design, Evaluation and Rehabilitation

Washington State Department of Transportation

June 1999

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June 1999

FOREWORD

This guide has been prepared for WSDOT personnel in designing, constructing and maintaining pavement structures. Volume 3 includes descriptions of four computer software programs and three case studies which will highlight the overlay and new design process.

The units used in this Volume will be metric and US customary. The three WSDOT computer programs – Everstress©, Evercalc©, and Everpave© – are capable of calculating in both US customary and in metric units. For this guide, the results of these three programs will be shown in metric. The AASHTO computer program DARWin, on the other hand, is currently capable of using only US customary units. Therefore, all output that is obtained from the DARWin computer program will be shown in US customary units, but will be converted to metric units then compared to the output of the other computer programs.

This volume does not constitute a WSDOT standard.

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Additional references for the Everseries© pavement analysis software programs can be found in the following publications:

1. Bu-Bushait, A., "Development of a Flexible Pavement Fatigue Model for Washington State", Ph. D. Dissertation, University of Washington, Seattle, Washington, 1985.
2. Newcomb, D. E., "Development and Evaluation of a Regression Method to Interpret Dynamic Pavement Deflections", Ph. D. Dissertation, University of Washington, Seattle, Washington, 1986.
3. Lee, S. W., "Backcalculation of Pavement Moduli by Use of Pavement Surface Deflections", Ph. D. Dissertation, University of Washington, Seattle, Washington, 1988.
4. Lee, S. W., Mahoney, J. P., and Jackson, N. C., "A Verification of Backcalculation of Pavement Moduli", *Transportation Research Board* No. 1196, Transportation Research Board, Washington DC, 1988.
5. Sivaneswaran, N., Kramer, S. L., and J. P. Mahoney, "Advanced Backcalculation Using a Nonlinear Least Squares Optimization Technique", *Transportation Research Board* No. 1293, Transportation Research Board, Washington DC, 1991.
6. Sivaneswaran, N., "Applications of System Identification in Geotechnical Engineering", Ph. D. Dissertation, University of Washington, Seattle, Washington, 1993.
7. Mahoney, J. P., Winters, B. C., Jackson, N. C., and Pierce, L. M., "Some Observations about Backcalculation and Use of a Stiff Layer Condition", *Transportation Research Board* No. 1384, Transportation Research Board, Washington DC, 1993.
8. Pierce, L. M., Jackson, N. C., and Mahoney, J. P., "Development and Implementation of a Mechanistic-Empirical Based Overlay Design Procedure for Flexible Pavements", *Transportation Research Board* No. 1388, Transportation Research Board, Washington DC, 1993.
9. Mahoney, J. P. and Pierce, L. M., "An Examination of WSDOT Transfer Functions for Mechanistic-Empirical AC Overlay Design", *Transportation Research Board* No. 1539, Transportation Research Board, Washington DC, 1996.
10. Pierce, L. M. and Mahoney, J. P., "Asphalt Concrete Overlay Design Case Studies", *Transportation Research Board* No. 1543, Transportation Research Board, Washington DC, 1996.

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The Washington State Department of Transportation does not warrantee anything concerning any of the programs or files which make up the Everseries© Pavement Analysis Programs. We accept no responsibility for any loss or damage of any kind which results from the use or purported use of the Everseries© Pavement Analysis Programs, or any files in the package, for any purpose whatsoever.

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SECTION 1.0

EVERSTRESS© — LAYERED ELASTIC ANALYSIS

This SECTION provides a discussion of the WSDOT pavement layered elastic analysis program Everstress ©.

1. INTRODUCTION

The Everstress© program is capable of determining the stresses, strains, and deflections in a layered elastic system (semi-infinite) under circular surface loads. The program can analyze a pavement structure containing up to five layers, 20 loads and 50 evaluation points. The Everstress© program will also take into account any stress dependent stiffness characteristics.

1.1 CHARACTERISTICS OF EVERSTRESS©

The program can be used to estimate stress, strain or deflection within a layered pavement system due to a static load(s). The modulus of elasticity, Poisson's ratio and thickness must be defined for each layer. Further, the load magnitude, contact pressure (or load radius) and location must be defined for each load (wheel) considered.

Everstress© was developed from WESLEA layered elastic analysis program (provided by the Waterways Experiment Station, U.S. Army Corps of Engineers). The pavement system model is multi-layered elastic using multiple wheel loads (up to 20). The program can analyze a pavement structure containing up to five layers and can consider the stress sensitive characteristics of unbound pavement materials.

The consideration of the stress sensitive characteristics of unbound materials can be achieved through adjusting the layer moduli in an iterative manner by use of stress-modulus relationships as follows [1.1]:

$$E_b = K1\ \theta^{K2} \text{ for granular soils,} \tag{1.1}$$

$$E_s = K3\ \sigma_d^{K4} \text{ for fine grained soils,} \tag{1.2}$$

E_b = resilient modulus of granular soils (MPa or ksi),
E_s = resilient modulus of fine grained soils (MPa or ksi),
θ = bulk stress (MPa or ksi),

σ_d = deviator stress (MPa or ksi), and
K1, K2, K3, K4 = regression constants

K1 and K3 are dependent on moisture content, which can change with the seasons. K2 and K4 are related to soil types, either coarse grained or fine-grained soil. K2 is positive and K4 is negative and remain relatively constant with the seasons.

Each iteration of the program, when stress dependent layers are used includes pavement analysis, modulus calculation and comparison, and modulus adjustment. The pavement analysis provides the stresses, strains, and deflections. The inspection points for the pavement analysis are typically, vertically at the bottom of the asphalt concrete layers, at mid-depth of unbound base and subbase courses, and at the top of subgrade. Inspection points can be placed as necessary by the user and are limited to a total of 50 inspection points.

Bulk stress is calculated for coarse grained soil layers, and deviator stress for fine grained soil layers. Required moduli are determined by use of the stress-modulus relationships (Equations 1.1 and 1.2), and compared to the moduli used for the pavement analysis. If the sum of modulus difference is less than allowable tolerance (an input requirement), then the program produces a solution. Otherwise, the iteration process is repeated until the modulus difference becomes less than the allowable tolerance or the iteration reaches the maximum allowable iteration (input requirement).

1.2 HARDWARE REQUIREMENTS

The Everstress© program is coded in Microsoft Visual Basic and Microsoft FORTRAN Power Station 4.0 and is designed to run on IBM or compatible personal computers with Microsoft Windows 95/NT 4.0 or higher.

1.3 INSTALLATION OF THE PROGRAM

To install the program, start Windows, click on the **Start** button, select Run and type a:\setup or select **Browse** and locate the SETUP.EXE. Prior to installation of the program(s) the user will be shown the README.TXT. It is highly recommended that this file be reviewed prior to the installation of the program(s). Once README.TXT has been reviewed, the user is asked to select the source directory (default - a:\), the target directory (default = C:\EVERSERS), and which programs are to be installed. The user has the option of selecting Everstress©, Evercalc©, Everpave©, or any combination of the above. Once satisfied with the selection, select **Start Install**

1.4 PROGRAM CONTENTS

The following paragraphs describe each of the various menus and inputs of the program.

1.4.1 FILE

Prepare Input Data - This menu option provides a form to create an INPUT DATA File or edit an existing file. INPUT DATA File contains layer information, load information, and evaluation points.

Analyze Pavement - This menu option performs the actual analysis and requires the INPUT DATA File. The analysis is carried out in a DOS window and it is advised that you don't switch windows until the completion of the Analysis.

Print/View Output - This menu option lets the user view the output on the screen and optionally print it on the Windows default printer.

Exit – This menu option closes the program and returns the user to the Windows desktop.

1.4.2 HELP

Contents – Contains descriptions of the various program menus and entry requirements for program operation. The help screen is derived from the field descriptions contained in this User's Guide.

Search for Help on… - Typical Windows format for searching for key program descriptions.

About Everstress© - lists program version information, responsible agency and personnel contacts, system memory and resources.

1.4.3 PREPARE INPUT DATA

1.4.3.1 File

Open – Open previously saved Data File.

Save - Save the current INPUT DATA File under the same name.

Save As - Save the current INPUT DATA File under a different name.

NOTE: The user must save all data entry files, the program will not automatically save any entries or prompt user to save file.

Exit - Exit Input Data Entry. Selecting exit will not prompt for saving. The user must save the data prior to exiting this screen.

1.4.3.2 Help

Contents – Contains descriptions of the various program menus and entry requirements for program operation. The help screen is derived from the field descriptions contained in this User's Guide.

Search for Help on… - Typical Windows format for searching for key program descriptions.

1.4.3.3 Entry Data

Title - Text for identification purposes.

No of Layers - Total number of layers in the pavement structure. The maximum number of layers is limited to five.

Units - Units of measurement, either metric or US Customary.

Layer Information

No - Layer number. The upper most layer is designated as number 1 and proceeds sequentially downward. This entry is for Everstress © file structure only and can not be edited by the user.

Layer ID - Identifies whether the moduli of the layer is stress sensitive

- *0* - Moduli is stress insensitive (AC material)
- *1* - Moduli varies with bulk stress (coarse grained soil)
  - $E = \text{Multiplier} \times (\text{Bulk Stress/Atmospheric Pressure})^{\text{Power}}$
- *2* - Moduli varies with deviator stress (fine grained soil)
  - $E = \text{Multiplier} \times (\text{Deviator Stress/Atmospheric Pressure})^{\text{Power}}$

<u>Note</u>

It was customary to use the following form of the equation to describe stress sensitive moduli:

Coarse Grained Material

$$E = \text{Multiplier} * (\text{Bulk Stress})^{\text{Power}}$$

Fine Grained Material

$$E = \text{Multiplier} * (\text{Deviator Stress})^{\text{Power}}$$

The new coefficients are related to these coefficients by the following relationships:

Power New = Power Old

$$\text{Multiplier New} = \text{Multiplier Old} * (\text{Atmospheric Pressure})^{\text{Power Old}}$$

Example:

$$E = 8500 * (\text{Bulk Stress})^{0.375} \text{ would be equivalent to}$$
$$E = 8500 * (14.696)^{0.375} * (\text{Bulk Stress/Atmospheric Pressure})^{0.375}$$

The atmospheric pressure is in the same units as the stress (101.4 kPa or 14.696 psi). The bulk and deviator stress includes static (overburden) stress. The stresses used are calculated at X = 0, Y = 0 and at the bottom of the 1st layer, at the middle of the intermediate layers, and at the top of the last layer. The loading locations should be specified with this in mind.

Interface Contact – Describes the frictional contact between layers.

Value	Description
0	full slip at the layer interface
1	Complete adhesion at the layer interface (no slip)
2 - 1000	Partial slip (also varies with E and Poisson's ratio)

Poisson's Ratio - Enter the Poisson's ratio for each layer. The following are typical values for Poisson's Ratio:

Asphalt Concrete Pavement	0.35
Crushed Surfacing Base	0.40
Subgrade	0.45

Thickness - Enter the thickness of each layer (cm or inches).

Moduli - Resilient modulus for each layer. If this layer is stress sensitive, this will be used as the initial moduli and the program will compute a stress compatible moduli iteratively (MPa or ksi).

Multiplier - If this layer is stress sensitive, use the multiplier regression coefficients as described in Layer ID above. If Layer ID is equal to zero, then this entry will not apply and the program will automatically remove the data box.

Power - If this layer is stress sensitive, use K2 or K4 regression coefficients. If Layer ID is equal to zero, then this entry will not apply and the program will automatically remove the data box.

Max. Iteration - If any of the layers are stress sensitive, the maximum number of iterations allowed in obtaining stress compatible moduli. A value of five is typical used.

Modulus Tol. (%) - If any of the layers are stress sensitive, modulus percentage tolerance in successive iterations. A value of 1.0 is typically used.

1.4.3.2 Load/Evaluation Locations

No. of Loads - Number of loads applied to the pavement structure. Currently the program is limited to a maximum of 20 loads.

No of X-Y Evaluation Points - Number of X-Y evaluation points. Currently the program is limited to a maximum of 50 points, this includes all combinations of X-Y and Z locations. For example, if the user enters five X-Y locations and three Z locations for each X-Y location, then the number of evaluation points is 5 (X-Y) x 3 (Z) = 15. Each X-Y point can have up to five points in the Z direction. If more than five points in the Z direction are needed at the same X-Y locations, then the next evaluation point can be used with the same X-Y locations.

X-Position - X coordinate of the load/evaluation point (cm or inches).

Y-Position - Y-coordinate of the load/evaluation point (cm or inches).

Z-Position - Z-coordinate of the evaluation point (cm or inches).

Load - Magnitude of the load (N or lb.).

Pressure - Contact pressure of the applied load (kPa or psi).

Radius - Radius of the loaded area.

NOTE: Only two of the above three (load, pressure, radius) are required, the third value will be automatically calculated (cm or inches).

1.4.3.3 Unit Weight

The unit weight of each material layer is required if any of the layer moduli are stress sensitive for the calculation of the overburden pressures. The program provides the following default values, which may be modified as necessary.

Layer No.	Layer Description	Unit Weight (kN/m^3)	Unit Weight (lbs/ft^3)
1	Asphalt Concrete	22.8	145.0
2	Crushed Stone Base	20.5	130.0
3	Subgrade	19.7	125.0
4	Subgrade	18.9	120.0
5	Subgrade	18.9	120.0

1.4.4 ANALYZE PAVEMENT

Performs the actual analysis. The program will prompt for the INPUT DATA File and an OUTPUT DATA File. The analysis is carried out in a DOS window and it is advised that you don't switch to other windows until the analysis is completed.

1.4.5 PRINT/VIEW RESULTS

This menu item allows the user to select the output Filename to be either reviewed on the screen or printed to the default Windows printer.

Options – standard Windows protocols are used for viewing various pages, zoom, selecting font style for screen view and printing, printing and exiting print screen.

Output Description - Most of the output quantities are self explanatory, except for the following:

Stresses - stresses due to input wheel load(s) (does not include overburden components).

Strains - strains do not include the static components.

Moduli (1) - moduli specified in the input data.

Moduli (2) - stress compatible moduli calculated (only for stress sensitive materials).

Maximum Error in Modulus - maximum error in the calculated moduli (stress compatible) at the end of the last iteration.

Sxx, Syy, Szz, Syz, Sxy, Sxz - normal stresses in the X-Y-Z directions.

Exx, Eyy, Ezz - normal strains in the X-Y-Z directions.

Ux, Uy, Uz - deflections in the X-Y-Z directions.

S1, S2, S3 - principal stress.

E1, E2, E2 - principal strains.

1.5 EXECUTION OF THE PROGRAM

As a general note, any time you save a file in Everstress ©, use the same extension as designated by the program. The program calls the required files according to their extension. It will save the user time and key strokes if the program extension protocols are followed.

After the user has started Windows, the program can be initiated by double clicking onto the Everstress© icon. The screen as shown in Figure 1.1 will be displayed.

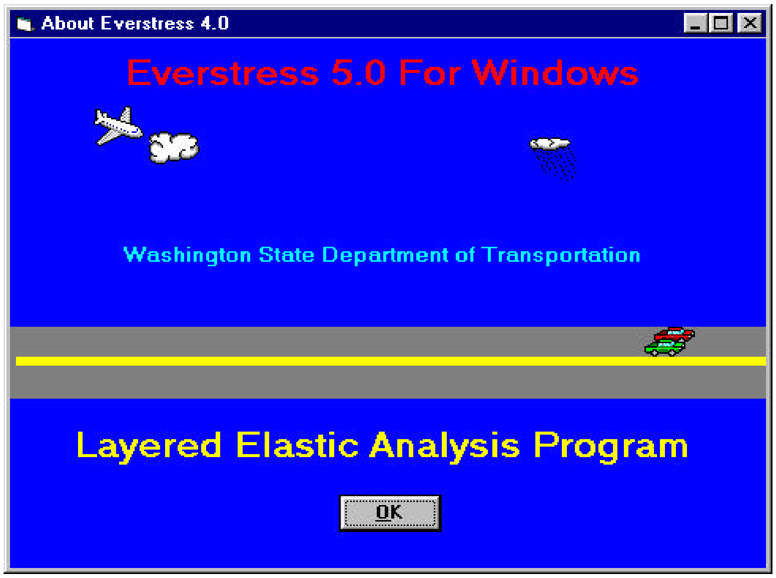

Figure 1.1. About Everstress© Screen

Press the **OK** button and the screen as shown in Figure 1.2 will be displayed.

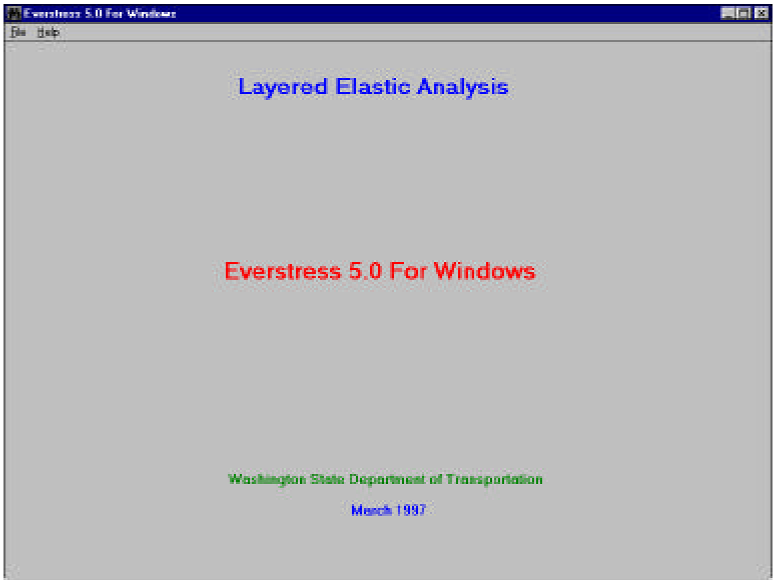

Figure 1.2. Everstress© Main Screen

To begin the analysis, select **File** and then select **Prepare Input Data**. The screen in Figure 1.3 will be shown.

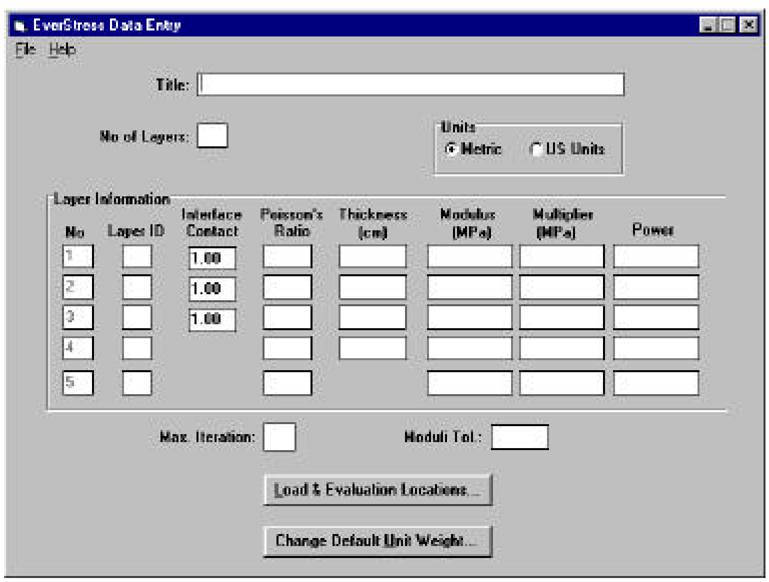

Figure 1.3. Everstress© Data Entry Screen

Begin by entering a job title, number of layers, type of units and the necessary layer data. Once all inputs have been entered, select **Load & Evaluation Locations** and the screen in Figure 1.4 will be shown.

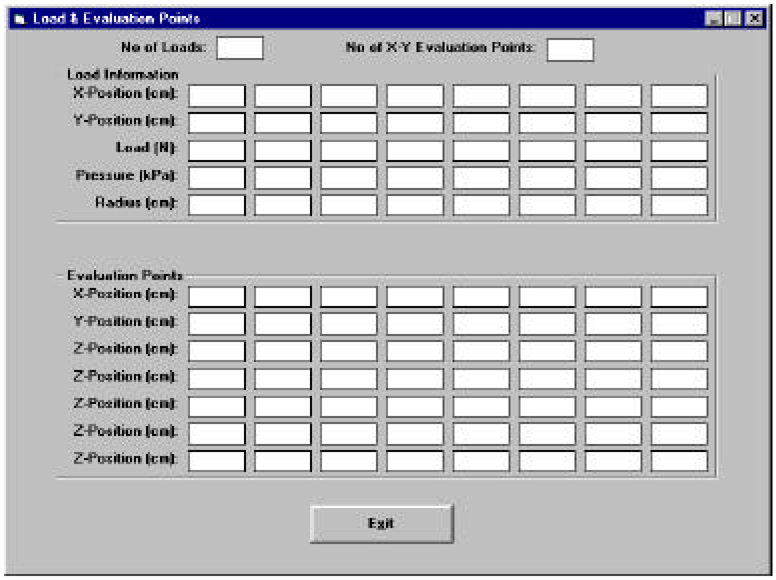

Figure 1.4. Everstress© Load & Evaluation Points Screen

This screen requires the number of loads, the number of X-Y evaluation points and the X-Y location of each load and evaluation point. The evaluation points will automatically be calculated from the layer thickness entered in the Data Entry Screen. The Z coordinates are set as default locations at the bottom of the AC layer, at mid-depth of the base course and at the top of the subgrade. In order to insure that the evaluation points are within the AC layer and the subgrade, 0.001 is subtracted from the AC depth and 0.001 is added to the AC plus Base depth. Once all data has been entered, select **Exit** to return to the Data Entry Screen.

To make changes to the default material unit weights, Select **Change Default Unit Weight**. The screen in Figure 1.5 will be shown. Unit weight values are recommended default values and can be modified as necessary. Select **Exit** to return to the Data Entry Screen.

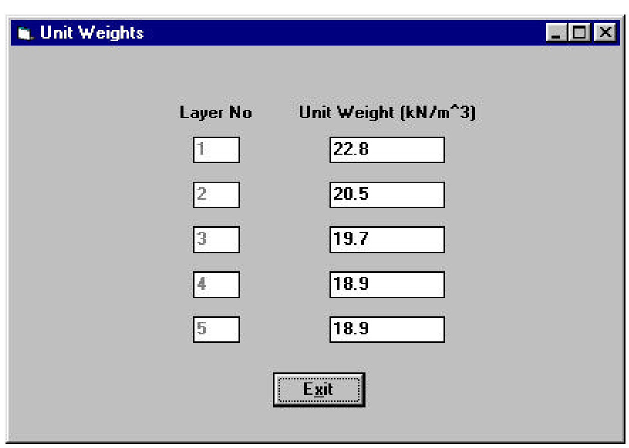

Figure 1.5. Everstress© Unit Weights Screen

After all data has been entered, the data must be saved. To save the data as a file, select **File** and then select **Save** and enter a filename (using the same extension as shown) and select **OK**.

To analyze the data, select **File** and then select **Analyze Pavement**. The program will then ask the user to select the INPUT DATA Filename. If the file was saved using the Everstress© protocol, then the filename will be shown on the screen. The user can then select the file by double clicking on the filename or by selecting the filename and then selecting **OK**. The program will then automatically create an output filename with ".OUT" as the extension, if this is correct, select **OK**. The program will begin the analysis and inform the user that it is processing the data. Once the analysis has been completed, a version of the following screen will be shown (see Figure 1.6). Note the program will display the word "Finished" in the lower left hand corner of the screen indicating that the analysis is complete. To exit this screen the user can either select **File** and **Exit** or click on the "X" box in the upper right hand corner of the screen.

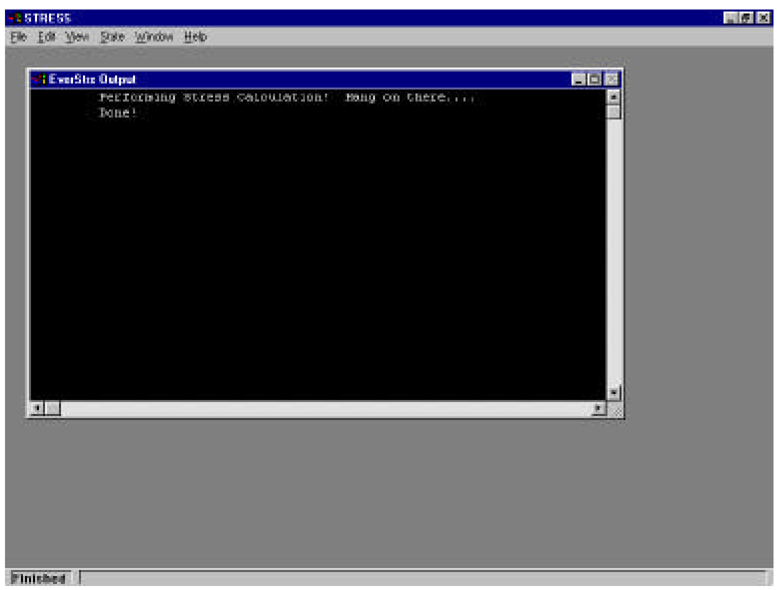

Figure 1.6. Analysis Completed Screen

To view/print the data, select **File** and then select **Print/View Results**. The computer program will ask the user to select the output filename to be viewed. Select the file by double clicking on the filename or by selecting the filename and then selecting **OK**. The file will be displayed on the screen and can be viewed by pressing the up and down arrows to scroll through a page or by pressing the page up and page down to move from one page to the next, or by pressing the left or right arrow buttons to move from one page to the next. The program allows the user to zoom in and out to better view the data. The preferred font may also be selected for viewing and printing of the data (this font will be set as the default font for future analysis). To print the file, select **Options** and **Print**. To return back to the Main screen select **Options** and **Exit**.

To exit the Everstress© program, select **File** and then select **Exit**.

1.6 EXAMPLE

Number of Layers = 3

Layer	Poisson's Ratio	Thickness (cm)	Modulus (MPa)
AC	0.35	10	2000
Base	0.40	15	175
Subgrade	0.45		85

Number of Loads = 2

Load	X-Position (cm)	Y-Position (cm)	Load (N)	Pressure (kPa)
1	0	0	20 000	700
2	0	40	20 000	700

Number of Evaluation Points = 3

X-Position (cm)	Y-Position (cm)	Z-Position #1 (cm)	Z-Position #2 (cm)	Z-Position #3 (cm)
0	0	9.999	17.500	25.001
0	20	9.999	17.500	25.001
0	40	9.999	17.500	25.001

1.6.1 PRINTOUT OF RESULTS

Layered Elastic Analysis by Everstress© for Windows

Title: EXAMPLE
No of Layers: 3 No of Loads: 2 No of X-Y Evaluation Points: 2

Layer	Poisson's Ratio	Thickness (cm)	Moduli (1) (MPa)
1	.35	10.000	2000.00
2	.40	15.000	175.00
3	.45		85.00

Load No	X-Position (cm)	Y-Position (cm)	Load (N)	Pressure (kPa)	Radius (cm)
1	.00	.00	20000.0	700.00	9.537
2	.00	40.00	20000.0	700.00	9.537

Location No: 1 X-Position (cm): .000 Y-Position (cm): .000

Normal Stresses

Z-Position (cm)	Layer	Sxx (kPa)	Syy (kPa)	Szz (kPa)	Syz (kPa)	Sxz (kPa)	Sxy (kPa)
9.999	1	1038.84	907.95	-182.03	12.46	.00	.00
17.500	2	16.02	2.11	-105.39	12.60	.00	.00
25.001	3	-6.39	-14.67	-68.99	9.11	.00	.00

Normal Strains and Deflections

Z-Position (cm)	Layer	Exx (kPa)	Eyy (kPa)	Ezz (kPa)	Ux (10^-6)	Uy (10^-6)	Uz (10^-6)
9.999	1	392.39	304.03	-431.71	.00	-14.73	545.49
17.500	2	327.61	216.33	-643.66	.00	-25.93	487.21
25.001	3	367.78	226.50	-700.21	.00	-37.01	442.95

Principal Stresses and Strains

Z-Position (cm)	Layer	S1 (kPa)	S2 (kPa)	S3 (kPa)	E1 (10^-6)	E2 (10^-6)	E3 (10^-6)
9.999	1	-182.18	908.09	1038.84	-431.80	304.13	392.39
17.500	2	-106.85	3.57	16.02	-655.32	227.99	327.60
25.001	3	-70.48	-13.18	-6.39	-725.57	251.86	367.78

Location No: 2 X-Position (cm): .000 Y-Position (cm): 20.000

Normal Stresses

Z-Position (cm)	Layer	Sxx (kPa)	Syy (kPa)	Szz (kPa)	Syz (kPa)	Sxz (kPa)	Sxy (kPa)
9.999	1	482.76	-93.11	-83.56	.00	.00	.00
17.500	2	16.83	-15.99	-77.44	.00	.00	.00
25.001	3	-6.91	-21.15	-66.37	.00	.00	.00

Normal Strains and Deflections

Z-Position (cm)	Layer	Exx (kPa)	Eyy (kPa)	Ezz (kPa)	Ux (10^-6)	Uy (10^-6)	Uz (10^-6)
9.999	1	272.29	-116.41	-109.97	.00	.00	530.54
17.500	2	309.76	47.14	-444.45	.00	.00	501.13
25.001	3	381.90	139.00	-631.96	.00	.00	464.81

Principal Stresses and Strains

Z-Position (cm)	Layer	S1 (kPa)	S2 (kPa)	S3 (kPa)	E1 (10^-6)	E2 (10^-6)	E3 (10^-6)
9.999	1	-93.11	-83.56	482.76	-116.41	-109.97	272.29
17.500	2	-77.44	-15.99	16.83	-444.45	47.14	309.76
25.001	3	-66.34	-21.15	-6.91	-631.96	139.00	381.90

Location No: 3 X-Position (cm): .000 Y-Position (cm): 40.000

Normal Stresses

Z-Position (cm)	Layer	Sxx (kPa)	Syy (kPa)	Szz (kPa)	Syz (kPa)	Sxz (kPa)	Sxy (kPa)
9.999	1	1038.84	907.95	-182.03	-12.46	.00	.00
17.500	2	16.02	2.11	-105.39	-12.60	.00	.00
25.001	3	-6.39	-14.67	-68.99	-9.11	.00	.00

Normal Strains and Deflections

Z-Position (cm)	Layer	Exx (kPa)	Eyy (kPa)	Ezz (kPa)	Ux (10^-6)	Uy (10^-6)	Uz (10^-6)
9.999	1	392.39	304.03	-431.71	.00	14.73	545.49
17.500	2	327.61	216.33	-643.66	.00	25.93	487.21
25.001	3	367.78	226.50	-700.21	.00	37.01	442.95

Principal Stresses and Strains

Z-Position (cm)	Layer	S1 (kPa)	S2 (kPa)	S3 (kPa)	E1 (10^-6)	E2 (10^-6)	E3 (10^-6)
9.999	1	-182.18	908.09	1038.84	-431.80	304.13	392.39
17.500	2	-106.85	3.57	16.02	-655.32	227.99	327.60
25.001	3	-70.48	-13.18	-6.39	-725.57	251.86	367.78

SECTION 1.0

REFERENCES

1.1 Michelow, J., Analysis of Stress and Displacements in an n-Layered Elastic System under a Load Uniformly Distributed on a Circular Area California Research Corporation, Richmond, California, 1963.

SECTION 2.0

EVERCALC© — PAVEMENT BACKCALCULATION

This SECTION provides a discussion of the WSDOT pavement layer backcalculation program Evercalc©.

1. INTRODUCTION

As discussed in Volume 2, SECTION 7.0, Paragraph 3.3, backcalculation is the process by which pavement layer moduli are determined by matching measured and calculated surface deflection basins. General backcalculation guidelines are contained in Appendix 2.1.

Evercalc© is a pavement analysis computer program that estimates the "elastic" moduli of pavement layers. Evercalc© estimates the elastic modulus for each pavement layer, determines the coefficients of stress sensitivity for unstabilized materials, stresses and strains at various depths, and optionally normalizes asphalt concrete modulus to a standard laboratory condition (temperature). Evercalc© uses an iterative approach in changing the moduli in a layered elastic solution to match theoretical and measured deflections. A simplified flow diagram of this method is shown in Figure 2.1.

1.1 CHARACTERISTICS OF EVERCALC©

1.1.1 GENERAL

The Evercalc© program uses WESLEA (provided by the Waterways Experiment Station, U. S. Army Corps of Engineers) as the layered elastic solution to compute the theoretical deflections and a modified Augmented Gauss-Newton algorithm for optimization. Basic assumptions of layered elastic theory include the following:

- Layers are infinitely long in the horizontal directions
- Layers have uniform thickness
- Bottom layer is semi infinite in the vertical direction
- Layers are composed of homogeneous, isotropic, linearly elastic materials, characterized by elastic modulus and Poisson's ratio.

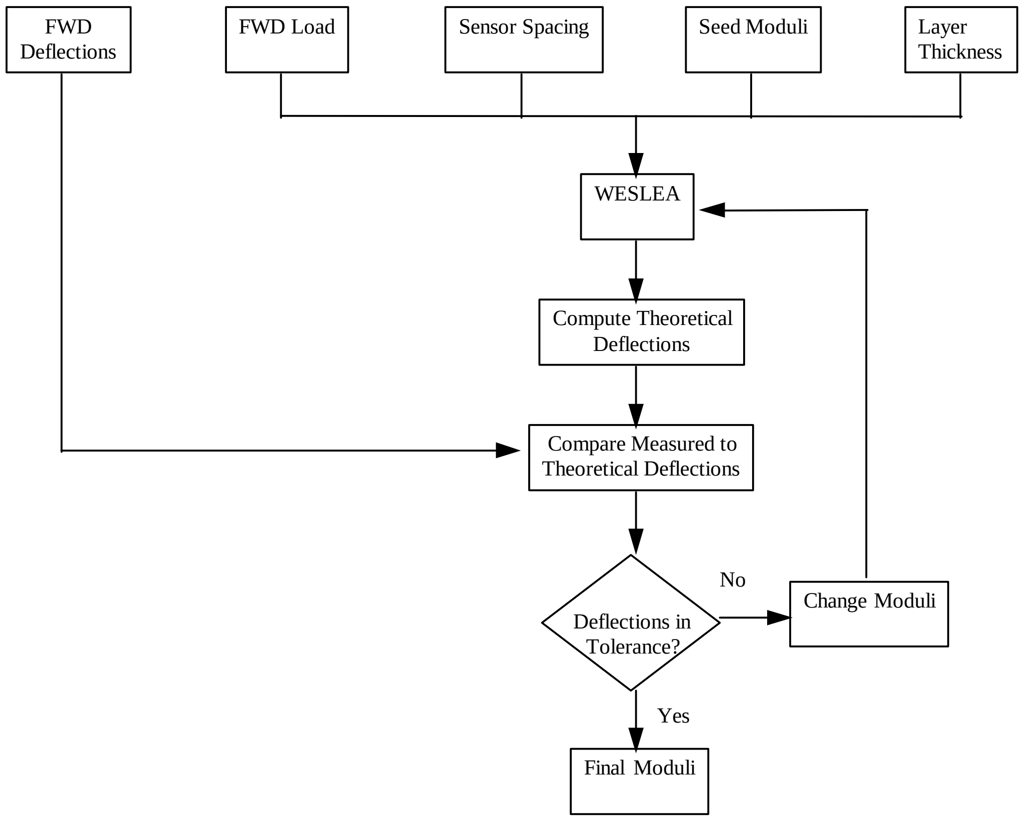

Figure 2.1. Simplified Flow Chart for Evercalc©

An inverse solution technique is used to determine elastic moduli from FWD pavement surface deflection measurements. The program can handle up to ten sensors and twelve drops per station. The program is capable of evaluating a flexible pavement structure containing up to five layers. From an initial, rough estimate of layer moduli (seed moduli), the program iteratively searches for the “final” modulus for each pavement layer. The deflections calculated using WESLEA are compared with the measured ones at each iteration. When the discrepancies in the calculated and measured deflections as characterized by root mean square (RMS) error (Equation 2.1), or the changes in modulus (Equation 2.2) falls within the allowable tolerance, or the number of iterations has reached a limit the program terminates. Using the final set of moduli, the stresses and strains at the bottom of the AC layer, middle of the other layers except the subgrade, and at the top of the subgrade are calculated. When deflection data for more than one load level is available at a given point, coefficients of stress sensitivity for unstabilized materials are also computed. Optionally, AC layer modulus is normalized to a standard laboratory condition.

1.1.2 SEED MODULI

Two options for estimating the seed moduli are available. When a pavement structure containing up to three layers is being analyzed, a set of internal regression equations can be used [2.1]. These regression equations determines a set of seed moduli from the relationships between the layer modulus, surface deflections, applied load, and layer thickness. Alternatively, the user can provide these values. When more than one deflection data set at a given location is analyzed, the final moduli from the previous deflection data set is used as seed moduli for the next one in order to improve the performance of the program.

1.1.3 TERMINATION

The program terminates when one or more of the following conditions are satisfied:

i) Deflection Tolerance:

$$\text{RMS }(\%) = \left(\sqrt{\frac{1}{n_d}\sum_{i=1}^{n}\left(\frac{d_{ci}-d_{mi}}{d_{mi}}\right)^2}\right)(100) \tag{2.1}$$

where, d_{ei} and d_{mi} are the measured and calculated deflections at i-th sensor and n- is the number of sensors.

Normally a deflection tolerance of one percent is considered adequate.

ii) Moduli Tolerance:

$$\varepsilon_m = \frac{[E_{(k+1)i} - E_{ki}] \text{ x } (100)}{E_{ki}} \tag{2.2}$$

where, E_{ki} and $E_{(k+1)i}$ are the i-th layer moduli at the k-th and (k+1)-th iteration, respectively, and m- is the number of layers with unknown moduli.

Again, a modulus tolerance of one percent is considered adequate.

iii) Number of iterations has reached the Maximum Number of Iterations. At every iteration a minimum of (m + 1) calls to WESLEA is made, where m- is the number of layers with unknown moduli. Normally, a maximum number of ten iterations is adequate.

1.1.4 COEFFICIENTS OF STRESS SENSITIVITY

The stress sensitivity characteristics of unstabilized material moduli are usually formulated as follows:

$$E_b = k_1\theta^{k_2} \text{ for coarse grained soils} \tag{2.3}$$

$$E_s = k_3\sigma_d^{k_4} \text{ for fine grained soils} \tag{2.4}$$

where, E_b = resilient modulus of coarse grained soils,
E_s = resilient modulus of fine grained soils,
θ = bulk stress,
σ_d = deviator stress, and
k_1, k_2, k_3, and k_4 = regression coefficients

The program determines the stress sensitivity coefficients using a linear regression method when FWD deflection data for two or more load levels at a given point are available.

1.1.5 TEMPERATURE CORRECTION

The stiffness of asphalt concrete is primarily affected by temperature and loading rate. While FWD loads occur over a 25 to 35 millisecond loading time (approximately) and at ambient temperature, the standard laboratory condition is taken to be a 25 °C (77°F) temperature and a 100 millisecond loading time. Thus, the stiffness of asphalt concrete can be normalized to view the backcalculated modulus in terms of the "traditional" laboratory values (at least this is what is being attempted).

Temperature normalization of asphalt concrete is accomplished using the relationship between the modulus and temperature. The relationship for WSDOT Class B asphalt concrete was found as follows [2.2]:

$$\log E_{ac} = 6.4721 - 1.47362 \times 10^{-4}(T_p)^2 \tag{2.5}$$

where, E_{ac} = modulus of asphalt concrete (psi), and
T_p = pavement temperature (°F)

From the above modulus-temperature relationship, the backcalculated AC modulus at the insitu field temperatures is multiplied by an adjustment factor in order to obtain a "standard" modulus at a temperature of 77° F:

$$TAF = 10^{0.000147362(Tp^2-77^2)} \tag{2.6}$$

where, TAF = temperature adjustment factor, and
T_p = pavement temperature (°F)

Pavement temperature is determined either by direct measurement or Southgate's method, which uses pavement surface temperature, the previous five-day mean temperature, and pavement thickness. Both measurement methods are incorporated in the program.

It should be noted that the temperature correction is based on regression equations that were developed for the WSDOT Class B asphalt concrete and its validity to other classes of asphalt concrete are not known. However, Class B is a traditional, typical dense asphalt concrete mixture.

1.1.6 DEPTH TO STIFF LAYER

A depth to stiff layer is estimated using the scheme reported by Rhode and Scullion [2.4]. The basic assumption is that no surface deflection will occur beyond the offset (measured from the load plate) which corresponds to the intercept of the applied stress zone and a stiff layer (the stiff layer modulus being 100 times larger than the subgrade modulus). Thus, the method for estimating the depth to stiff layer assumes that the depth at which zero deflection occurs (presumably due to a stiff layer) is related to the offset at which zero deflection occurs.

This feature in Evercalc© is optional within the GENERAL DATA File (to be discussed in later SECTIONS). It is common to expect a stiff layer condition within a 10-meter depth. Accounting for a stiff layer condition generally reduces the subgrade modulus (layer above the stiff layer) and increases the base course modulus. If multiple deflection basins and associated loads exist at a specific station, the program calculates the depth to stiff layer for each basin adjusted to a 40 kN (9000 lb) load. The mean depth and associated standard deviation is calculated. Any depths outside of the limits of the mean ± the standard deviation are removed and the mean depth recalculated. This depth is then used in the subsequent layer moduli calculations at that station. If only one deflection basin and associated load is used, then the program linearly adjusts the required deflections to a 40 kN (9000 lb) load to estimate the depth to stiff layer. Refer to Volume 2, SECTION 7.0, Paragraph 3.3.4 for additional information on the depth to stiff layer.

1.2 HARDWARE REQUIREMENTS

The Evercalc© program is coded in Microsoft Visual Basic and Microsoft FORTRAN Power Station 4.0 and designed to run on IBM or compatible personal computers with Microsoft Windows 95/NT 4.0 or higher.

1.3 INSTALLATION OF THE PROGRAM

To install the program, start Windows, click on the **Start** button, select Run and type a:\setup or select **Browse** and locate SETUP.EXE. Prior to installation of the program(s) the user will be shown the README.TXT. It is highly recommended that this file be reviewed prior to the installation of the program(s). Once README.TXT has been reviewed, the user is asked to select the source directory (default - a:\), the target directory (default = C:\EVERSERS), and which programs are to be installed. The user has the option of selecting Everstress©, Evercalc©, Everpave©, or any combination of the above. Once satisfied with the selection, select **Start Install**.

1.4 PROGRAM CONTENTS

The following paragraphs describe each of the various menus and inputs of the program.

1.4.1 FILE

Open GENERAL DATA File - This menu option provides a form to create a new GENERAL DATA File or edit an existing one. GENERAL DATA File contains information that does not change from station to station, such as load plate radius, unit, sensor offsets, etc.

Open DEFLECTION DATA File - This menu option provides a form to create a new DEFLECTION DATA File or edit an existing one. This menu option requires an existing GENERAL DATA File. The DEFLECTION DATA File contains station specific data such as layer thickness, pavement temperature, number of drops, plate load and sensor deflection for each drop.

Perform Backcalculation - This menu option performs the backcalculation process. This menu option requires the GENERAL DATA File and DEFLECTION DATA File. Backcalculation is carried out in a DOS window and it is advised that you don't switch windows until the completion of backcalculation. If the Stiff Layer option is used, then depth to stiff layer is calculated first and then the actual backcalculation is performed. Backcalculation can be performed in either interactive or batch mode.

Interactive Mode: In interactive mode, the backcalculation is carried out in the foreground and the progress during each iteration and the calculated and measured deflection basins at the end of iteration are displayed on the screen

Batch Mode: In batch mode, the backcalculation is carried out in the background. The iteration details are saved in a log file having the same name as the DEFLECTION DATA File with the extension .LOG.

If stiff layer option is used the user is presented with a histogram and a table of depth to apparent stiff layer and with the station identifier. The user can choose to accept the calculated depth to stiff layer values or modify it before performing the backcalculation.

Convert FWD DATA File - This menu option converts a raw FWD (Dynatest Model 8000) data file to an Evercalc© DEFLECTION DATA File. This menu option requires an existing GENERAL DATA File. If the deflection data is generated from any other NDT device, other than the Dynatest 8000, this option will not generate the appropriate file format.

Modify Standard Temperature – Since asphalt materials are temperature sensitive and FWD data collection temperature may vary within a specific location and from one location to the next, the establishment of a standard temperature is necessary. WSDOT default standard temperature for the determination of the asphalt moduli to be 25°C (77° F).

Exit – Exit the program and return to the Windows screen.

1.4.2 PRINT

1.4.2.1 Print/View Output

Displays formatted output data on the screen and provides the option to print on the default printer. The output data contains all calculations for all required iterations and can result in at least 2 pages per station.

Options – standard Windows protocols are used for viewing various pages, zoom, selecting font style for screen view and printing, printing and exiting print screen.

1.4.2.2 Print/View Summary

Displays formatted summary data on the screen and provides the option to print on the default printer. This data contains the station, layer thickness, moduli for each specified layer, the RMS error.

Options – standard Windows protocols are used for viewing various pages, zoom, selecting font style for screen view and printing, printing and exiting print screen.

1.4.2.3 Page Setup

Allows the user to modify the page margins. The default settings are shown.

1.4.2.4 Select Font

Allows the user to choose any available font for use in displaying and printing the output and summary information. This font is also saved as the default font for future output display.

1.4.3 HELP

Contents – Contains descriptions of the various program menus and entry requirements for program operation. The help screen is derived from the field descriptions contained in this User's Guide.

Search for Help on… - Typical Windows format for searching for key program descriptions.

About Evercalc© - lists program version information, responsible agency and personnel contacts, system memory and resources.

1.4.4 OPEN GENERAL FILE

Title - Any text that describes the GENERAL DATA File

No of Layers - Total number of layers (including the stiff layer, if a stiff layer option is selected). The minimum number of layers is two, and the maximum number of layers is five. Seed moduli will need to be provided if the number of layers is more than three.

No of Sensors - Total number of FWD sensors. Maximum number of sensors is limited to ten.

Units - Units of measurement and output, either Metric or US Customary.

Stiff Layer - Check this option to include a stiff layer. The depth to stiff layer is calculated prior to beginning the backcalculation process. The stiff layer moduli should be provided.

Temp. Correction - Check this option to adjust the moduli of the first layer to the standard temperature.

Temp. Measurement - Required only when temperature correction is required. Select the appropriate temperature measurement option. Choose the Direct Method option if using an asphalt concrete mid-depth temperature measurement. Use the Southgate Method option if pavement temperature is to be calculated from surface temperatures and five-day mean air temperatures (requires additional data).

Plate Radius - Radius of the FWD loading plate.

Seed Moduli - Seed moduli are the initial estimates of unknown layer moduli. Choose Internal if you want the program to estimate the seed moduli. The internal option cannot be used when the number of layers is more than three. The user can also specify seed moduli by selecting User Supplied.

Sensor Weigh Factor – This field allows the user to select amongst three options for calculating the error function that drives the backcalculation process. Evercalc© uses uniform as the default method. The three options are described as follows:

- Uniform: Each sensor deflection is weighed uniformly in constructing the error function. The error being minimized is:

$$100\sqrt{\frac{\sum_{i-1}^{N}\left(\frac{dm-dc}{dm}\right)^{2}}{N}}$$

- Inverse First Sensor: Each sensor is weighed by the inverse of the first sensor deflection. The error being minimized is:

$$100\sqrt{\frac{\sum_{i-1}^{N}\left(\frac{dm}{d1}\left(\frac{dm-dc}{dm}\right)\right)^{2}}{N}} \quad \text{or} \quad 100\sqrt{\frac{\sum_{i-1}^{N}\left(\frac{dm-dc}{d1}\right)^{2}}{N}}$$

- User Supplied: User specified weigh factors. User must provide weigh factors for each sensor. The error being minimized is:

$$100\sqrt{\frac{\sum_{i-1}^{N}\left(wm\left(\frac{dm-dc}{dm}\right)\right)^{2}}{N}}$$

where, d1 = measured deflection at load cell
d2 = measured deflection at 20 cm (8 in) from load cell
dc = calculated deflections
dm = measured deflections
wm = user specified weighing factor
N = number of loads

Note: The RMS error reported in the output and summary output are always calculated with uniform weight -i.e.:

$$\text{RMS Error} = 100\sqrt{\frac{\sum_{i-1}^{N}\left(\frac{dm-dc}{dm}\right)^{2}}{N}}$$

This is done so that the convergence can be compared regardless of the weighing factor used.

Radial Offsets - Radial offsets of the sensors from the center of the loading plate.

Layer Information

No - Layer number. The upper most layer is designated as number one and proceeds sequentially downward.

Layer ID - Enter 0 if the moduli of this layer is to be backcalculated (unknown moduli). Enter 1 if the moduli of this layer is fixed (known).

Poisson's Ratio - Enter the Poisson's ratio of this layer.

Initial Moduli - Enter seed moduli for this layer if the User Supplied option is selected for Seed Moduli or 0.0 if the Internal option is selected.

Min. Moduli - Enter the minimum value of the layer moduli for this layer (must be greater than or equal to 0.0). Can be set to 0.0 if no minimum limit is required.

Max. Moduli - Enter the maximum value of the layer moduli for this layer (must be greater than or equal to 0.0). Can be set to 0.0 if no minimum limit is required.

Max. Iteration - Maximum number of iterations allowed during the optimization. A value of ten is typically used.

RMS Tol. (%) - Root mean square error tolerance between the measured and calculated deflections (percentage). A value of 1.0 is typical.

Modulus Tol. (%) - Modulus percentage tolerance in successive iterations. A value of 1.0 is typical.

Stress and Strain Location – allows user to input up to 10 locations for stress and strain computation. The default locations are beneath the center load at the bottom of the asphalt layer, at the middle of the base layer, and at the top of the subgrade.

Save - Saves the current GENERAL DATA File under the same name. The user must save the file after the data is entered. The program will not save automatically or prompt user to save the data file.

Save As - Saves the current GENERAL DATA File under a different name.

Cancel - Discards any changes made without saving and returns the user to the Main Screen.

1.4.5 OPEN DEFLECTION DATA FILE

Route - Name of the Route or any other descriptive information.

Station Information

Station **-** Station identification, such as milepost. A maximum character limit of ten.

H(1) to H(4) - Thickness of each pavement layer, up to 5 layers. The last layer thickness is excluded (subgrade or stiff layer are considered to be infinite in depth).

No. of Drops - Total number of drops at this station. A maximum of 16 drops is allowed.

Pavement Temperature - Pavement temperature (if Direct Method) or five day mean air temperature (if Southgate Method).

Deflection Information

Drop No – The drop number if more than one drop is input. The program allows up to eight drops per station.

Load - Plate load for each drop.

Sensor Deflection - Measured sensor deflection for each drop at each sensor starting from the closest sensor to the farthest sensor.

Add Station - Adds a station after the current station.

Plot – Allows user to view and print data plots of deflection basins (per station and all load levels), layer thickness, and normalized deflections (standard load of 80 kN (9,000 lbs)).

Delete Station - Deletes the current station.

Save - Saves the current DEFLECTION DATA File. The user must save the data file, the program will not automatically save or prompt the user to save the data file.

Save As - Saves the current DEFLECTION DATA File under a different name.

Cancel - Discards any changes made without saving and returns the user to the Main screen.

1.4.6 PERFORM BACKCALCULATION

Interactive – this option requires user to initiate backcalculation process.

Batch – the option allows the user to backcalculate without requiring user intervention for completion. This option will turn off the iteration graphics so that multiple analysis can be started one after another. After starting one analysis the user can start additional analysis by selecting the batch mode menu item. However, all analyses are run in the background sharing the same computer resources and the CPU and memory limitation will dictate the number of analysis that can be started simultaneously.

1.4.7 FWD CONVERSION

GENERAL DATA File – Name of the GENERAL DATA File.

FWD DATA File - Name of the FWD raw data file including its path. Recall that this feature is only available with the Dynatest 8000 FWD's (version 20).

DEFLECTION DATA File - Name of the DEFLECTION DATA File where the converted FWD data will be saved.

Project Data – this information (route name, number of layers, number of sensors, etc.) will automatically be displayed and is the contents of the GENERAL DATA File. The station locations will also be displayed based on the specified FWD DATA File.

Layer Thickness Information - FWD raw data file does not contain layer thickness information. When the user chooses an FWD file to be processed, a table is displayed with station identifiers in the first column (non-editable), selection option in the second column, and columns for thicknesses for each of the layers excluding the last layer and stiff layer, if any. The user can choose to include or exclude selected stations from the FWD file by clicking the "Selected" column to be checked on or off, respectively. If the stationing is alphanumeric then thicknesses should be provided for all stations selected for backcalculation. If the stationing is numeric then thicknesses need only be provided where it changes and the layer thicknesses for each station (mile post) in the FWD raw data file is chosen to be the same as that of the closest previous station from this list of thicknesses. A minimum of one set of data needs to be provided.

If layer thickness does not change through the project length, the user only needs to enter layer thickness at the first station. If various layer thickness depths exist, the user is only required to enter thicknesses where changes occur. For example, project limits are from station 0 to station 5, and the following layer thickness exist:

Station	Thickness of Asphalt H(1)	Thickness of Base H(2)
0	10 cm	15 cm

2.5	15 cm	20 cm

The user would then click on box adjacent to Station 0 and then type in 10 for H(1) and 15 for H(2). The same process would then be necessary next to station 2.5, click on the box adjacent to Station 2.5 and type in 15 for H(1) and 20 for H(2). The program will then use 10 cm for the asphalt layer and 15 cm for the base layer from Station 0 to Station 2.5, and 15 cm for the asphalt layer and 20 cm for the base layer from Station 2.5 to Station 5.0.

Select All – Selects all station locations for layer moduli determination.

Deselect All – Deselects all station locations. User selects specific locations for layer moduli determination.

Multiple Drops – Allows user various methods for analyzing data when multiple drops at the same load level are collected.

No – use all the load-deflection data in the backcalculation process. This option is recommended when only one drop per load level has been collected.

Average Normalized – FWD data was collected using multiple drops at each load level. The average load at each load level is determined and then the deflections are averaged and normalized at each load level. For this method the user must enter the number of drops per load. For example, the deflection data is collected using three drops at each load level. This option would then calculate the average load for all three drops (for each load level), then each of the three deflection readings are normalized to the average load and then the normalized deflections are averaged to obtain a single load-deflection data at that load level.

Average – FWD data was collected using multiple drops at each load level. This method averages the load and deflection data. For this method the user must enter the number of drops per load. If the deflection data was collected using multiple drops at each load level, this is the recommended procedure to minimize the random error that is associated with deflection and/or load measurements.

Convert - Converts the FWD raw data file to the necessary format. This process is extremely quick and the user is not prompted that the process is complete.

Exit – Exits the Convert screen and returns to the main screen.

Temperature Information

If Direct Method of temperature correction is selected in the General Data file, then the Asphalt Temperature will be extracted from the FWD file. If Southgate Method is selected in the General Data file, then the Pavement Surface Temperature and the Air Temperature will be extracted form the FWD file.

Please see the Dynatest FWD FILED PROGRAM Edition 20 file format sheet for additional information. If any of these fields are blank in the FWD file then they will be treated as 0.0 and the user should modify/validate this in the Deflection Data form.

1.4.8 Modify Standard Temperature

Allows user to modify the standard temperature for determining the asphalt layer moduli. WSDOT uses 25°C (77°F) as the standard temperature.

1.4.9 Exit

Exits the program and returns to Windows.

1.5 EXECUTION OF THE PROGRAM

As a general note, any time you save a file in Evercalc©, use the same extension as designated by the program. The program calls the required files according to their extension. It will save the user time and key strokes if the program extension protocols are followed. In addition, the program will not automatically save any data, the user must click on the "Save" or "Save As" buttons once data has been entered.

After the user has started Windows, the program can be initiated by double clicking on the Evercalc© icon. The screen as shown in Figure 2.1 will be displayed.

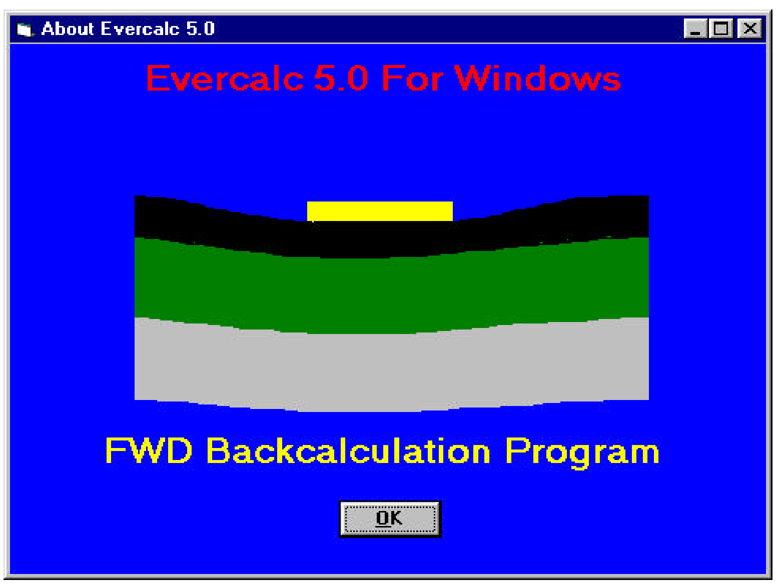

Figure 2.1 About Evercalc© Screen

Press the **OK** button and the screen as shown in Figure 2.2 will be displayed. After a few moments the program will automatically close the screen shown in Figure 2.1.

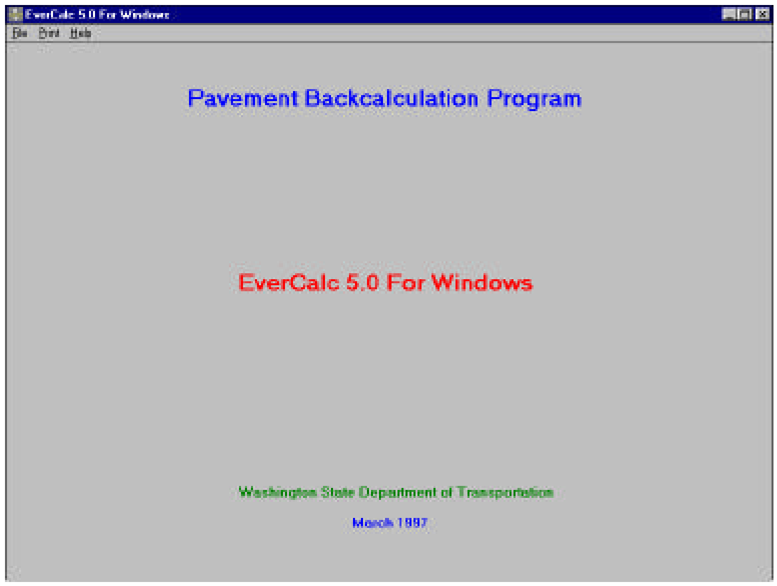

Figure 2.2. Evercalc© Main Screen

The first step for performing the backcalculation process is the development of the GENERAL DATA File. The GENERAL DATA File contains general pavement data and the general specifications of the nondestructive testing device. Select **File** and then select **Open General File** to create the GENERAL DATA File. The program will prompt the user for a filename, either select a file that is listed or enter a nonexistent filename to create a new GENERAL DATA File. Once the file has been generated the screen as shown in Figure 2.3 will be displayed.

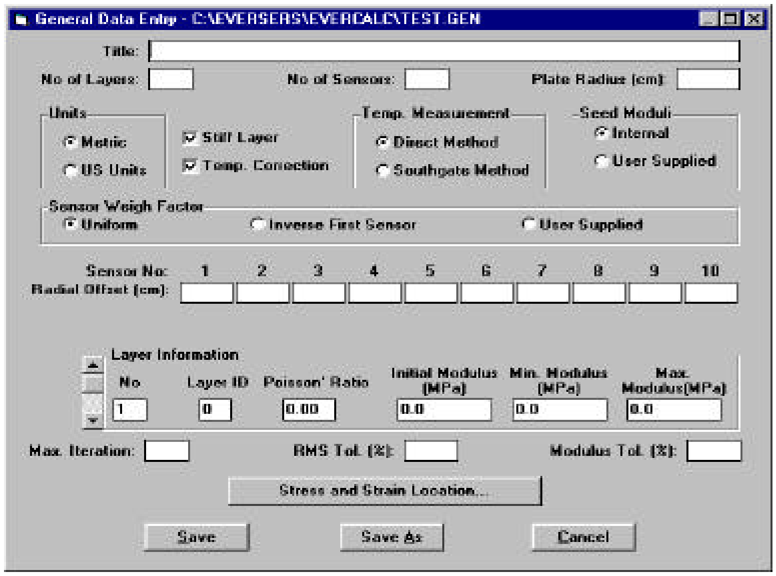

Figure 2.3. General Data Entry Screen

Begin by entering the following data:

- The title of the project
- The number of pavement layers. The number of layers is limited to five layers, including a stiff layer, if used
- The number of FWD sensors
- The radius of the FWD loading plate
- The units of measure
- Presence of a stiff layer?
- Is temperature correction desired for the asphalt concrete layer? Default value for temperature correction is 25°C (77°F) or can be established by the user by selecting **File** and **Modify Standard Temperature**.
- Pavement temperature measured using the Direct or Southgate Method?
- Are the seed moduli to be internal or user supplied? If a stiff layer is used, the user must supply the seed (initial) moduli.
- What sensor weigh factor will be used?
- The radial offset (cm or inches) of each sensor from the load plate. WSDOT uses the following sensor spacing: 0 cm, 20.3 cm (8 inches), 30.5 cm (12 inches), 61.0 cm (24 inches), 91.5 cm (36 inches), and 122.0 cm (48 inches). Care must be taken to insure that the most distant sensor from the load is actually measuring a deflection. If this sensor is located too far from the loading plate, the sensor may pick up more "noise" than an actual deflection and may result in higher error than necessary.

- Layer information. Using the scroll bar, input the layer number, layer ID, Poisson's ratio, initial modulus (MPa or ksi), and if supplied by the user, the minimum and maximum moduli (MPa or ksi) for each of the pavement layers.
- Enter the program termination values: maximum number of iterations, RMS tolerance (in percent) and the modulus tolerance (in percent).
- Modify stress and strain locations, if necessary.
- Prior to exiting this screen the data must be saved. Select the **Save** button and the data will be saved using the same filename. Selecting the **Save As** button will save the data as a different filename. Selecting the **Cancel** button will return the user to the Main Screen without saving any modifications to the file.

Following the creation of the GENERAL DATA File, the user must then create the DEFLECTION DATA File. The DEFLECTION DATA File contains the data collected from the nondestructive testing device. There are two methods of entering deflection data. The first method is by "hand" entering the load and deflection data. The second method is by converting a raw FWD (Dynatest 8000 version 20 only) data file. The latter of these two will be described later. To "hand" enter in the load and deflection data, select **File** and then select **Open DEFLECTION DATA File**. The user will be prompted to select the GENERAL DATA File to be used (the GENERAL DATA File must have already been created). Then the user will be prompted to open an existing DEFLECTION DATA File or to create a new DEFLECTION DATA File by entering a nonexistent filename. Once the file has been generated the following screen as shown in Figure 2.4 will be displayed.

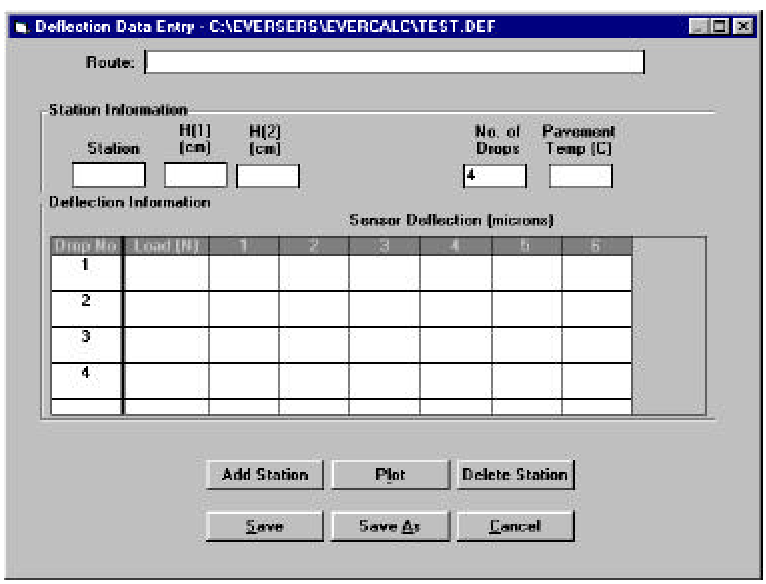

Figure 2.4. Deflection Data Entry Screen

At this screen, enter in the following data:

- Route, which can be any text that identifies the project.
- Station or milepost number, thickness of the asphalt concrete layer, thickness of the base layer, subbase layer(s) (if appropriate) number of drops, and the pavement temperature at the time of testing.
- For each station, enter the load(s) and the corresponding deflections.
- Additional stations may be added by selecting the **Add Station** button. Likewise, a station that is currently shown can be deleted by selecting the **Delete Station** button.
- Prior to exiting this screen the data must be saved. Select the **Save** button and the data will be saved using the same filename. Selecting the **Save As** button will save the data as a different filename. Selecting the **Cancel** button will return the user to the Main Screen without saving any modifications to the file.

To convert a raw FWD DATA File to a DEFLECTION DATA File, select file and then select **Convert FWD DATA File**. The user will be prompted to select the GENERAL DATA File and the FWD DATA File to be converted. The screen similar to what is shown in Figure 2.5 will be displayed.

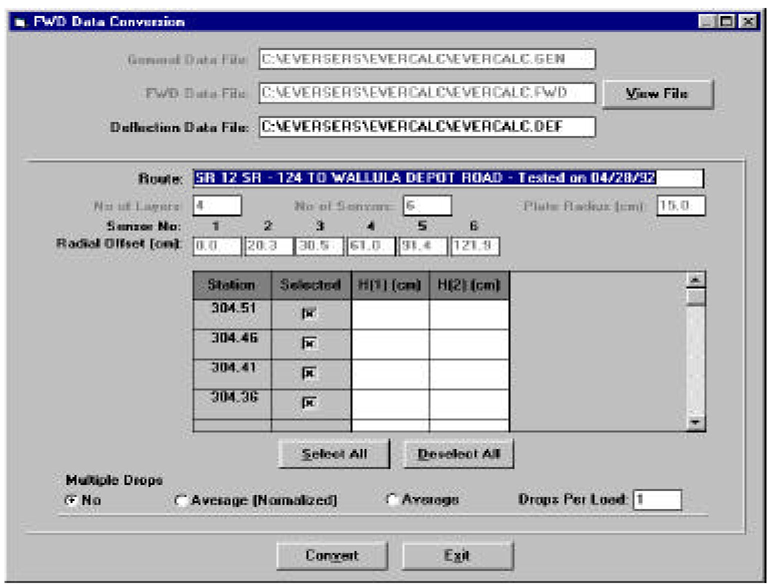

Figure 2.5 FWD Data Conversion Screen

The GENERAL DATA File and FWD DATA File that was selected by the user will be shown on the upper portion of this screen. The program will automatically name the DEFLECTION DATA File according to the name used for the FWD DATA File. The program will assign ".DEF" as the DEFLECTION DATA File extension. This screen will convert the raw FWD file into a format to be used in the backcalculation process.

In addition, this screen will allow the user to input layer thickness for each of the layers as designated in the GENERAL DATA File. The stations to be included in the deflection data file are selected and the corresponding layer thicknesses are entered as explained earlier. Once all data has been entered, select **Convert** and the program will execute, and then select **Exit** to return to the Main screen.

The plot routines that are available in the **Deflection Data Entry** screen are deflection basin, layer thickness, and normalized deflection. Selecting the Plot button, the following screen will be displayed.

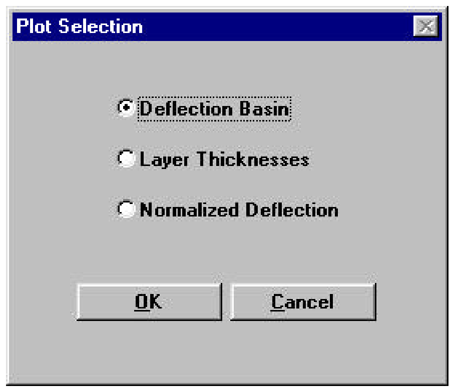

Figure 2.6. Deflection Data Plot Screen.

Each one of these options will be briefly described.

Deflection Basin – the deflection basin (for all load levels) will be displayed for each individual station location. The buttons across the top of the screen will allow the user various options for presenting the data.

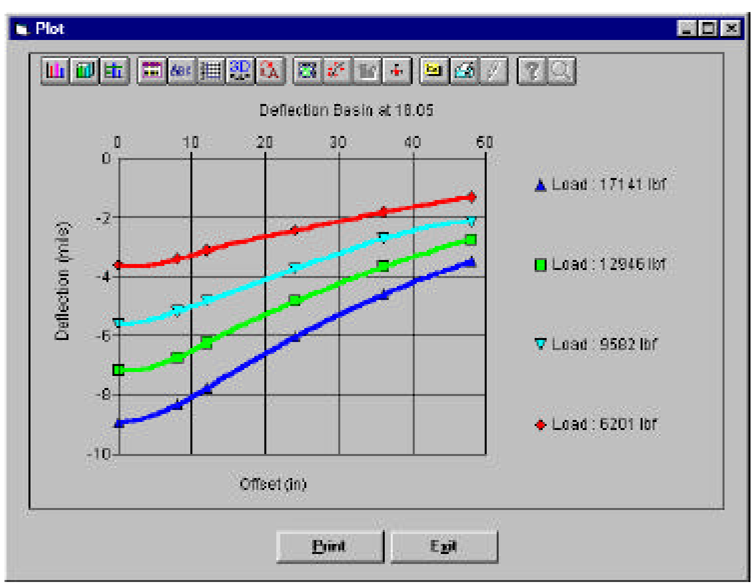

Figure 2.7. Plot Deflection Basin

Layer Thickness –the various layer thicknesses for the entire deflection data file will be displayed.

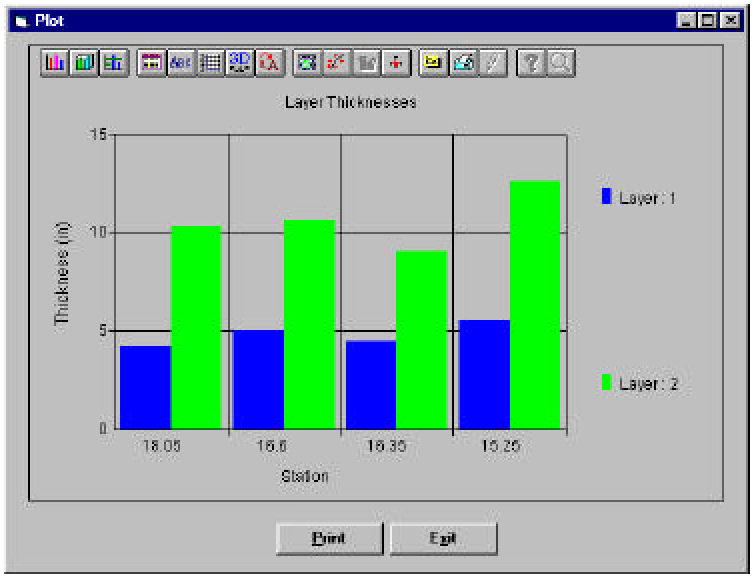

Figure 2.8. Plot Layer Thickness

Normalized Deflection – the normalized (to the standard temperature and 40 kN (9000 lb)) deflection will be displayed according to each sensor for the entire deflection data file.

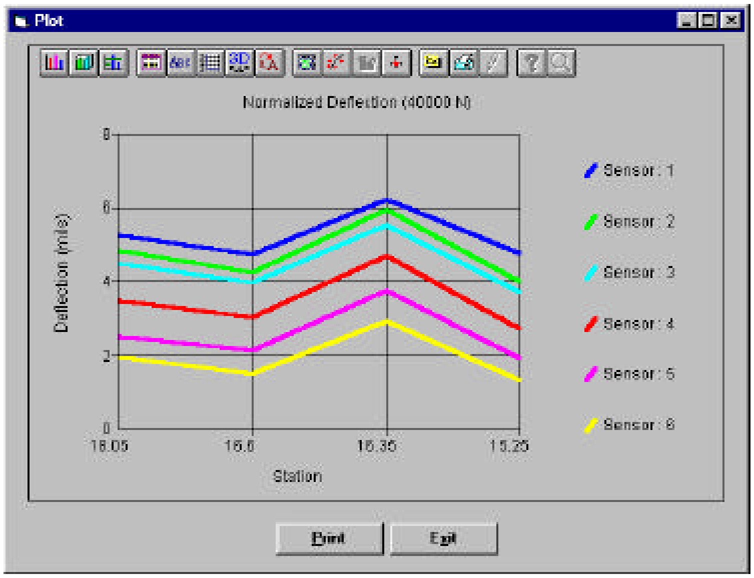

Figure 2.9. Plot Normalized Deflections

After creating the GENERAL DATA File and the DEFLECTION DATA File, the user is now able to begin the backcalculation process. Select **File** and then select **Perform Backcalculation**. The user will then have the choice to either run the backcalculation in the interactive or batch mode. If numerous deflection files are to be analyzed and the user does not want to be prompted to complete the analysis (run process over night for example) then the batch mode should be selected. In the interactive mode, the user will be prompted to select the GENERAL DATA File, the DEFLECTION DATA File, and to confirm the Output Filename. If the user selected to not use a stiff layer (GENERAL DATA File), the backcalculation process will begin. If the user selected a stiff layer, then the depth to stiff layer screen will be displayed and the user will be asked to modify the estimated depth to stiff layer or to accept the data as shown (see Figure 2.10).

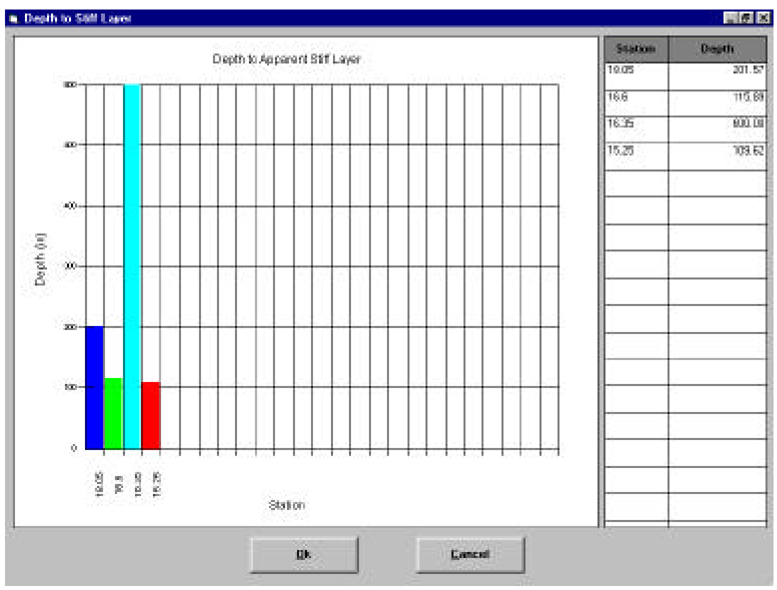

Figure 2.10. Depth to Apparent Stiff Layer Screen.

If the user has actual borings to depth of stiff layer (or saturated layer) they can be entered directly onto this screen. Clicking on the depth to be modified will allow the user to enter the necessary values.

Click on the **OK** button and the backcalculation process will begin. The program will then display on the screen the measured and calculated deflections in the determination of the layer moduli. The computer will display this screen for each load level at each station. The process is completed when the word “Finished” is displayed in the lower left-hand corner as shown in Figure 2.11.

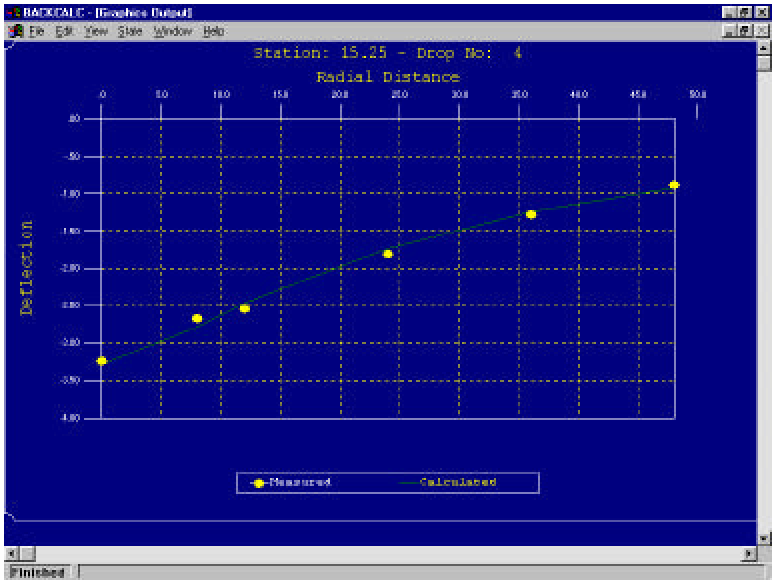

Figure 2.11. Backcalculation Screen

To return back to the main menu, select **File** and then **Exit** or close the screen using the X button in the upper right hand corner. The data can then be viewed or printed by selecting **Print** on the main menu tool bar. To exit the Evercalc© program, select **File** and then select **Exit**.

1.6 EVERCALC DEFLECTION FILE FORMAT

1.6.1 SAMPLE OF EVERCALC© 5.0 DEFLECTION FILE

```
SR 14 6TH AVE. TO EVERGREEN BLVD. - Tested on 12/06/95
18.05  4  4.200 10.320 0.000 0.000 37.000 0.000
17141.0 8.910 8.320 7.760 6.040 4.600 3.460
12946.0 7.150 6.720 6.220 4.830 3.650 2.720
9582.0 5.590 5.160 4.800 3.730 2.690 2.110
6201.0 3.590 3.390 3.100 2.420 1.800 1.290
16.6  4  5.000 10.560 0.000 0.000 37.000 0.000
16240.0 8.280 7.400 6.970 5.320 3.800 2.690
12279.0 6.460 5.810 5.440 4.150 2.980 2.080
9077.0 4.770 4.280 4.020 3.050 2.160 1.520
5883.0 2.900 2.680 2.480 1.880 1.330 0.830
16.35  4  4.500 9.000 0.000 0.000 37.000 0.000
15819.0 11.010 10.290 9.870 8.250 6.650 5.280
12180.0 8.620 8.240 7.690 6.540 5.260 4.120
9284.0 6.450 6.160 5.710 4.850 3.890 3.030
6062.0 3.980 3.930 3.690 3.060 2.430 1.940
15.25  4  5.500 12.600 0.000 0.000 37.000 0.000
```

```
15735.0 8.240 6.980 6.410 4.720 3.390 2.410
12204.0 6.570 5.570 5.070 3.770 2.670 1.880
9320.0 4.960 4.170 3.880 2.810 2.000 1.390
6030.0 3.240 2.670 2.540 1.810 1.280 0.880
```

1.6.2 FILE DESCRIPTION

The file is in free format – the values should be separated by a space, comma or hard TAB.

Line 1 – Route information (CHARACTER STRING, max length = 80)
Line 2
Item 1 – station (CHARACTER STRING, max length = 10)
Item 2 – number of drops at this station (Integer)
Item 3 through Item 6 – four layer thickness' (single precision). If there are less than four thickness' (i.e. less than five layers), enter 0.0 for the rest. For example, for a three layer case, enter the 1st and 2nd layer thickness first then enter 0.0 for the next two (cm or in).
Item 7 through Item 8 – temperature values (single precision). The temperature correction is defined in the GENERAL DATA File. If no temperature correction than enter 0.0 for both. If direct method then enter the temperature for Item 7 and enter 0.0 for Item 8. If Southgate method then enter surface temperature for Item 7 and mean temperature for Item 8 (°C or °F).

The following line is repeated for each drop at this station (defined in Line 2, Item 2)

Line 3
Item 1 – Plate load (single precision) (N or lbf)
Item 2 – Item ? deflections (single precision). Enter as many deflection readings as the number of sensors defined in the GENERAL DATA File, starting from the sensor closest to the load plat to the farthest (microns or mils)

The units should be consistent with that defined in the GENERAL DATA File. You can open this file in Evercalc© 5.0 (Open Deflection Data) and check for its correctness.

1.7 EXAMPLE NO. 1 — NO STIFF LAYER

1.7.1 GENERAL DATA FILE

Number of layers = 3
No stiff layer
Temperature measurement = Direct Method
Seed Moduli = User Supplied
Plate Radius = 15 cm

Sensor Number	1	2	3	4	5	6
Radial Offset (cm)	0	203	305	610	915	1220

Layer Information

No	Layer ID	Poisson's Ratio	Initial Modulus (kPa)	Minimum Modulus (kPa)	Maximum Modulus (kPa)
1	0	0.35	2 800 000	700 000	14 000 000
2	0	0.40	180 000	35 000	3 500 000
3	0	0.45	100 000	35 000	3 500 000

Maximum Iteration = 10
RMS Tolerance (%) = 1.0
Modulus Tolerance (%) = 1.0

1.7.2 DEFLECTION DATA FILE

Station = 210.00
H(1) = 10 cm
H(2) = 40 cm
Number of drops = 4
Pavement Temperature = 10°C

Drop Number	Load (N)	1	2	3	4	5	6
1	74 364	914	742	639	426	285	197
2	53 480	706	574	490	323	213	145
3	41 909	567	457	388	250	162	111
4	27 446	385	307	256	160	101	70

1.7.3 BACKCALCULATION RESULTS (NO STIFF LAYER)

1.7.3.1 Summary Output

BACKCALCULATION by Evercalc© 5.0 - Summary Output

Route: Example No. 1 - No Stiff Layer
Plate Radius (cm): 15.0
No of Sensors: 6
Offsets (cm) 0.0 20.3 30.5 61.0 91.5 122.0

No of Layers: 3
Stiff Layer: No
P-Ratio: .350 .400 .450

Station	Load (N)	Eadj(MPa)	E(1)(MPa)	E(2)(MPa)	E(3)(MPa)	RMS Error
210	Thickness (cm)	-	10.00	40.00	-	-

210	74364.0	3395.0	10868.0	117.7	83.0	2.38
210	53480.0	3233.7	10351.6	98.7	80.9	2.46
210	41909.0	2859.1	9152.4	98.8	82.3	2.28
210	27446.0	2346.9	7512.8	99.6	84.8	2.10
210	Norm.	2791.5	8936.0	98.9	82.6	2.31

1.7.3.2 Detail Output

BACKCALCULATION by Evercalc© 5.0 - Detail Output

Route: Example No. 1 - No Stiff Layer
Plate Radius (cm): 15.0 — No. of Layers: 3
No of Sensors: 6 — Stiff Layer: No
Offsets (cm) .0 20.3 30.5 61.0 91.5 122.0 — P-Ratio: .350 .400 .450

Station: 210 — No of Drops: 4 — Average RMS Error (%): 2.31
Thickness (cm): 10.00 40.00 — Pavement Temperature (C): 10.0

Drop No: 1 — Load (N): 74364.0 — No of Iterations: 4
Convergence: Modulus Tolerance Satisfied — RMS Error (%): 2.30

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	914.000	742.000	639.000	426.000	285.000	197.000
Calculated Deflection (microns):	885.566	756.495	657.409	418.408	278.517	200.925
Difference (%):	3.11	-1.95	-2.88	1.78	2.27	-1.99

Layer No:	1	2	3	1-(adj)
Seed Moduli (MPa)	3496.07	344.83	86.37	N/A
Calculated Moduli (MPa):	10867.97	117.73	83.02	3395.035

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-179.21	-95.32	-55.73
Radial Stress (kPa):	5319.76	-6.67	-5.97
Bulk Stress (kPa):	10460.30	-108.66	-67.67
Deviator Stress (kPa):	-5498.97	-88.66	-49.75
Vertical Strain (10^-6):	-359.13	-764.42	-606.47
Radial Strain (10^-6):	323.94	289.91	262.48

Drop No: 2 — Load (N): 53480.0 — No of Iterations: 3
Convergence: Modulus Tolerance Satisfied — RMS Error (%): 2.46

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	706.000	574.000	490.000	323.000	213.000	145.000
Calculated Deflection (microns):	683.375	583.404	506.042	317.792	207.741	147.914
Difference (%):	3.20	-1.64	-3.27	1.61	2.47	-2.01

Layer No:	1	2	3	1-(adj)

Seed Moduli (MPa)	10867.97	117.73	83.02	N/A
Calculated Moduli (MPa):	10351.59	98.73	80.87	3233.722

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-121.23	-67.15	-40.84
Radial Stress (kPa):	3940.95	-6.94	-4.91
Bulk Stress (kPa):	7760.67	-81.02	-50.66
Deviator Stress (kPa):	-4062.18	-60.22	-35.93
Vertical Strain (10^-6):	-278.21	-623.95	-450.28
Radial Strain (10^-6):	251.56	229.91	193.82

Drop No: 3 Load (N): 41909.0 No of Iterations: 2
Convergence: Modulus Tolerance Satisfied RMS Error (%): 2.28

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	567.000	457.000	388.000	250.000	162.000	111.000
Calculated Deflection (microns):	549.956	464.636	399.600	245.513	158.818	112.990
Difference (%):	3.01	-1.67	-2.99	1.79	1.96	-1.79

Layer No:	1	2	3	1-(adj)
Seed Moduli (MPa)	10351.59	98.73	80.87	N/A
Calculated Moduli (MPa):	9152.42	98.77	82.32	2859.115

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-101.94	-55.67	-33.49
Radial Stress (kPa):	2967.18	-5.60	-3.87
Bulk Stress (kPa):	5832.42	-66.88	-41.23
Deviator Stress (kPa):	-3069.12	-50.07	-29.63
Vertical Strain (10^-6):	-238.08	-518.27	-364.57
Radial Strain (10^-6):	214.63	191.42	157.25

Drop No: 4 Load (N): 27446.0 No of Iterations: 2
Convergence: Modulus Tolerance Satisfied RMS Error (%): 2.10

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	385.000	307.000	256.000	160.000	101.000	70.000
Calculated Deflection (microns):	374.886	311.071	263.680	156.397	99.760	71.061
Difference (%):	2.63	-1.33	-3.00	2.25	1.23	-1.52

Layer No:	1	2	3	1-(adj)
Seed Moduli (MPa)	9152.42	98.77	82.32	N/A
Calculated Moduli (MPa):	7512.77	99.61	84.77	2346.906

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-74.88	-39.87	-23.53
Radial Stress (kPa):	1813.27	-3.78	-2.53

Bulk Stress (kPa):	3551.66	-47.43	-28.58
Deviator Stress (kPa):	-1888.16	-36.09	-21.00
Vertical Strain (10^-6):	-178.92	-369.90	-250.72
Radial Strain (10^-6):	160.37	137.33	108.50

Layer No:	1	2	3	1-(adj)
Mean Moduli (MPa)	9471.19	103.71	82.75	2958.69
Normalized Moduli (MPa)	8936.00	98.88	82.65	2791.508
K1 (MPa):	N/A	106.49	80.16	
K2:	N/A	.23	-.03	
R-Squared:	N/A	75.66	51.14	
Soil Type:	N/A	Coarse	Fine	

1.8 EXAMPLE NO. 2 — STIFF LAYER AT 350 MPA

1.8.1 GENERAL DATA FILE

Number of layers = 4
Stiff layer
Temperature measurement = Direct Method
Seed Moduli = User Supplied
Plate Radius = 15 cm

Sensor Number	1	2	3	4	5	6
Radial Offset (cm)	0	203	305	610	915	1220

Layer Information

No	Layer ID	Poisson's Ratio	Initial Modulus (kPa)	Minimum Modulus (kPa)	Maximum Modulus (kPa)
1	0	0.35	2 800 000	700 000	14 000 000
2	0	0.40	180 000	35 000	3 500 000
3	0	0.45	100 000	35 000	3 500 000
4	1	0.20	350 000		

Maximum Iteration = 10
RMS Tolerance (%) = 1.0
Modulus Tolerance (%) = 1.0

1.8.2 DEFLECTION DATA FILE

Station = 210.00
H(1) = 10 cm
H(2) = 40 cm
Number of drops = 4
Pavement Temperature = 10°C

Drop Number	Load (kPa)	1	2	3	4	5	6
1	1054	914	742	639	426	285	197
2	758	706	574	490	323	213	145
3	594	567	457	388	250	162	111
4	389	385	307	256	160	101	70

1.8.3 BACKCALCULATION RESULTS

1.8.3.1 Summary Output

BACKCALCULATION by Evercalc© 5.0 - Summary Output

Route: Example No. 1 - Stiff Layer
Plate Radius (cm): 15.0
No of Sensors: 6
Offsets (cm) 0.0 20.3 30.5 61.0 91.5 122.0

No of Layers: 4
Stiff Layer: Yes
P-Ratio: .350 .400 .450 .200

Station	Load (N)	Eadj(MPa)	E(1)(MPa)	E(2)(MPa)	E(3)(MPa)	E(4)(MPa)	RMS Error
210	Thickness (cm)	-	10.00	40.00	797.48	-	-
210	74364.0	2788.7	8927.1	158.7	69.8	350.0	1.90
210	53480.0	2678.1	8572.8	134.5	67.8	350.0	1.98
210	41909.0	2373.5	7597.7	131.7	69.3	350.0	1.77
210	27446.0	1949.4	6240.3	128.9	71.9	350.0	1.59
210	Norm.	2317.5	7418.6	131.3	69.7	350.0	1.81

1.8.3.2 Detail Output

BACKCALCULATION by Evercalc© 5.0 - Detail Output

Route: Example No. 1 - Stiff Layer
Plate Radius (cm): 15.0
No of Sensors: 6
Offsets (cm) .0 20.3 30.5 61.0 91.5 122.0

No. of Layers: 4
Stiff Layer: Yes
P-Ratio: .350 .400 .450 .200

Station: 210
Thickness (cm): 10.00 40.00 797.48

No of Drops: 4

Average RMS Error (%): 1.81
Pavement Temperature (C): 10.0

Drop No: 1
Convergence: Modulus Tolerance Satisfied

Load (N): 74364.0

No of Iterations: 5
RMS Error (%): 1.90

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	914.000	742.000	639.000	426.000	285.000	197.000
Calculated Deflection (microns):	893.859	754.926	652.557	417.225	280.780	200.322
Difference (%):	2.20	-1.74	-2.12	2.06	1.48	-1.69

Layer No:	1	2	3	4	1-(adj)
Seed Moduli (MPa)	2800.00	180.00	100.00	350.0	N/A
Calculated Moduli (MPa):	8927.10	158.73	69.76	350.0	2788.727

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-229.47	-105.33	-52.32
Radial Stress (kPa):	4608.73	5.27	-3.69
Bulk Stress (kPa):	8987.98	-94.79	-59.69
Deviator Stress (kPa):	-4838.19	-110.60	-48.63

Vertical Strain (10^-6):	-387.09	-690.17	-702.37
Radial Strain (10^-6):	344.57	285.36	308.41

Drop No: 2 Load (N): 53480.0 No of Iterations: 3
Convergence: Modulus Tolerance Satisfied RMS Error (%): 1.98

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	706.000	574.000	490.000	323.000	213.000	145.000
Calculated Deflection (microns):	689.798	582.367	502.389	316.640	209.385	147.549
Difference (%):	2.29	-1.46	-2.53	1.97	1.70	-1.76

Layer No:	1	2	3	4	1-(adj)
Seed Moduli (MPa)	8927.10	158.73	69.76	350.0	N/A
Calculated Moduli (MPa):	8572.82	134.52	67.81	350.0	2678.053

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-155.22	-74.22	-38.74
Radial Stress (kPa):	3445.07	1.08	-3.05
Bulk Stress (kPa):	6734.93	-72.05	-44.84
Deviator Stress (kPa):	-3600.29	-75.30	-35.69
Vertical Strain (10^-6):	-299.41	-558.14	-530.72
Radial Strain (10^-6):	267.55	225.51	232.30

Drop No: 3 Load (N): 41909.0 No of Iterations: 2
Convergence: Modulus Tolerance Satisfied RMS Error (%): 2.28

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	567.000	457.000	388.000	250.000	162.000	111.000
Calculated Deflection (microns):	555.177	463.647	396.550	244.800	160.239	112.58
Difference (%):	2.09	-1.45	-2.20	2.08	1.09	-1.42

Layer No:	1	2	3	4	1-(adj)
Seed Moduli (MPa)	8572.82	134.52	67.81	350.00	N/A
Calculated Moduli (MPa):	7597.74	131.71	69.35	350.00	2373.451

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-128.76	-61.16	-31.83
Radial Stress (kPa):	2593.26	.44	-2.42
Bulk Stress (kPa):	5057.75	-60.28	-36.68
Deviator Stress (kPa):	-2722.01	-61.60	-29.40
Vertical Strain (10^-6):	-255.87	-467.02	-427.51
Radial Strain (10^-6):	227.79	187.74	187.31

Drop No: 4 Load (N): 27446.0 No of Iterations: 2
Convergence: Modulus Tolerance Satisfied RMS Error (%): 1.59

Sensor No:	1	2	3	4	5	6
Measured Deflection (microns):	385.000	307.000	256.000	160.000	101.000	70.000
Calculated Deflection (microns):	378.570	310.216	261.460	156.147	100.823	70.656
Difference (%):	1.67	-1.05	-2.13	2.41	.18	-.94

Layer No:	1	2	3	4	1-(adj)
Seed Moduli (MPa)	7597.74	131.71	69.35	350.00	N/A
Calculated Moduli (MPa):	6240.26	128.94	71.88	350.00	1949.387

Layer No:	1	2	3
Radial Distance (cm):	0.00	0.00	0.00
Position	Bottom	Middle	Top
Vertical Stress (kPa):	-92.90	-43.46	-22.41
Radial Stress (kPa):	1580.03	-.02	-1.60
Bulk Stress (kPa):	3067.16	-43.51	-25.61
Deviator Stress (kPa):	-1672.94	-43.44	-20.81
Vertical Strain (10^-6):	-192.13	-336.96	-291.67
Radial Strain (10^-6):	169.79	134.74	128.02

Layer No:	1	2	3	4	1-(adj)
Mean Moduli (MPa)	7834.48	138.47	69.70	350.00	2447.400
Normalized Moduli (MPa)	7418.57	131.35	69.68	350.00	2317.478
K1 (MPa):	N/A	147.99	66.51	N/A	
K2:	N/A	.32	-.04	N/A	
R-Squared:	N/A	88.23	59.66	N/A	
Soil Type:	N/A	Coarse	Fine	N/A	

SECTION 2.0

REFERENCES

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SECTION 3.0

EVERPAVE© — PAVEMENT OVERLAY DESIGN

This SECTION provides a discussion of the WSDOT Empirical-Mechanistic Overlay Design program Everpave ©.

1. INTRODUCTION

Everpave© is a flexible pavement overlay design program based on mechanistic analysis. Everpave© is based on the multilayered elastic analysis program, WESLEA (provided by the Waterways Experiment Station, U. S. Army Corps of Engineers), which produces the pavement response parameters such as stresses, strains, and deformations in the pavement system [3.1].

The determination of the overlay thickness is based on the required thickness to bring the damage levels to an acceptable level under a design traffic condition. The damage levels are based on two primary distress types, fatigue cracking and rutting, which are the most common criteria for mechanistic analysis based overlay design. The program is also capable of considering seasonal variations and stress sensitivity of the pavement materials.

1.1 CHARACTERISTICS OF EVERPAVE©

The program determines overlay thickness based on fatigue cracking and rutting failure criteria, which are both commonly used for mechanistic analysis. A pavement system under dual tire loads is analyzed by a multilayered elastic program (Everstress ©) which can consider stress sensitivity of unbound materials. The analysis produces the two failure criterion parameters, which are the horizontal tensile strain at the bottom of the asphalt concrete layer and the vertical compressive strain at the top of the subgrade for fatigue and rutting failures, respectively [3.2]. The program is also capable of considering four seasons.

For fatigue cracking failure, Finn's model is commonly used [3.3]. The model used linearly shifts Monismith's laboratory model which is shown below [3.4]:

$$\log N_f = 14.82 - 3.291 \log (\in_t) - 0.854 \log (E_{ac}) \qquad (3.1)$$

where,

N_f = loads to failure,

$\in_t$ = initial tensile strain (in/in x 10^{-6}),
E_{ac} = the stiffness of asphalt bound material (ksi)

However, this model creates two concerns for overlay design. One is the shift factor, which is for the adjustment of this laboratory relationship to a field condition, and the other is the tensile strain parameter.

A wide range of the shift factors were found in the literature [3.5]. The shift factor depends on asphalt concrete properties such as void ratio, type of asphalt cement, viscosity, pavement thickness, etc. [3.5,3.6]. The shift factor recommended for Washington State ranges from about four to ten.

The second concern is the tensile strain. It is not always clear if the strain at the bottom of the new overlay or that at the bottom of the existing pavement controls. Some design procedures utilize the strain at the bottom of the new asphalt concrete layer, the others at the bottom of the existing one or both [3.7,3.8,3.9,3.10,3.11]. If only the strain at the bottom of new asphalt concrete is used, the fatigue performance of a very thin overlay is unrealistic. Further, it is apparent that the strain in the old asphalt concrete layer affects the fatigue performance of pavement. Thus, both strains were incorporated in the fatigue performance estimate in the program.

Rutting occurs due to permanent deformation of the asphalt concrete layer and unbound layers. However, as the deformation of asphalt concrete is not well defined, the failure criteria equations are expressed as a function of the vertical compressive strain at the top of the subgrade. The Chevron equation was utilized [3.12]. It is shown below:

$$\log N_f = 1.077 \times 10^{18} (\in_{vs})^{-4.4843} \tag{3.2}$$

where,

N_f = loads to cause a 0.75 inch rut,
$\in_{va}$ = vertical compressive strain (in/in x 10^{-6}),

The traffic volume and the performance herein are always expressed in terms of 80 kN (18,000 lb) equivalent single axle loads (ESAL's).

The properties of the pavement system are significantly affected by climatic conditions, consequently, seasonal adjustments for pavement materials are essential for design purposes. The adjustment for asphalt concrete is achieved by the use of a stiffness-temperature relationship and that for the unbound materials by applying the seasonal variations of the materials (in terms of moduli ratio's). As the climate condition changes with location and time and its effects vary with pavement materials, engineering judgment is always needed.

As the stiffness of asphalt concrete is significantly affected by temperature, it is important to determine pavement temperature as accurately as possible. The pavement temperature is commonly determined by the relationship between air temperature and pavement temperature. For the pavement design purpose, monthly mean air temperature are utilized as follows [3.13]:

$$MMPT = MMAT \{1 + 1/(Z + 4)\} - 34/(Z + 4) + 6 \quad (3.3)$$

where,

MMPT = mean monthly pavement temperature (°F),
MMAT = mean monthly air temperature (°F), and
Z = depth below pavement surface (inches)

The integration of the overlay design procedures was accomplished in the following sequence:

1. Read input data including initial overlay thickness
2. Adjust pavement materials for seasonal moduli variations.
3. Analyze the pavement system and determine the two failure criteria parameters.
4. Compute allowable repetitions to failure, compare the design traffic to the allowable load repetitions, and calculate the damage ratio for each season.
5. Repeat Step 2, 3, and 4 for the four seasons.
6. Compute the sum of the seasonal damage ratio.
7. If the sum of the damage ratio is less than or equal to one, produce the overlay thickness. Otherwise, increase the overlay thickness and repeat Steps 2 through 7 until the sum of the damage ratio becomes less than or equal to one.

1.2 HARDWARE REQUIREMENTS

The Evercalc© program is coded in Microsoft Visual Basic and Microsoft FORTRAN Power Station 4.0 and designed to run on IBM or compatible personal computers with Microsoft Windows 95/NT 4.0 or higher.

1.3 INSTALLATION OF THE PROGRAM

To install the program, start Windows and at the Program File Manager select Run and type a:\setup. Prior to installation of the program(s) the user will be shown the

README.TXT. It is highly recommended that this file be reviewed prior to the installation of the program(s). Once README.TXT has been reviewed, the user is asked to select the source directory (default - a:\), the target directory (default = C:\EVERSERS), and which programs are to be installed. The user has the option of selecting Everstress©, Evercalc©, Everpave©, or any combination of the above. Once satisfied with the selection, select **Start Install**.

1.4 PROGRAM CONTENTS

The following paragraphs describe each of the various menus and inputs of the program:

1.4.1 FILE MENU

Prepare General Data - creates the GENERAL DATA File or edit an existing one. GENERAL DATA File contains truck and pavement data, such as, the design tire load and pressure, spacing of dual tires, fatigue shift factor for old and new AC, and the seasonal variation parameters.

Prepare Traffic Data - creates the TRAFFIC DATA File or edit an existing one. TRAFFIC DATA File contains information to determine the number of 80 kN (18,000 lb) equivalent single axle loads (ESAL's) for the design period. Traffic data can be entered according to the total traffic volume, annual traffic, or average daily traffic.

Prepare Pavement Data – creates the PAVEMENT DATA File or edit an existing one. The pavement data includes parameters related to the pavement structure, such as, pavement section location, material type, stress sensitivity coefficients, Poisson's ratio, layer thickness, etc.

Analyze Pavement - This menu option performs the overlay design. The GENERAL DATA File, TRAFFIC DATA File, and PAVEMENT DATA File must be created before this option is selected. **Print/View Results** - This menu item allows the user to view the output on the screen and print the output on the Windows default printer.

Modify Standard Values – This menu item is used to change the standard temperature and the fatigue and rutting equation coefficients.

Exit – This command closes the program and returns the user to the Windows screen.

1.4.2 HELP

Contents – Contains descriptions of the various program menus and entry requirements for program operation. The help screen is derived from the field descriptions contained in this User's Guide.

Search for Help on… - Typical Windows format for searching for key program descriptions.

About Everpave© - lists program version information, responsible agency and personnel contacts, system memory and resources.

1.4.3 PREPARE GENERAL DATA

1.4.3.1 File

Open - Open an existing GENERAL DATA File.

Save - Save the current GENERAL DATA File under the same name.

Save As - Save the current GENERAL DATA File under a different name.

Exit - Exit general data entry. Does not prompt for saving.

1.4.3.2 Help

Contents – Contains descriptions of the various program menus and entry requirements for program operation. The help screen is derived from the field descriptions contained in this User's Guide.

Search for Help on… - Typical Windows format for searching for key program descriptions.

1.4.3.3 General Data

Title - Any descriptive text for identification purposes.

Units - Units of measurement and output, either metric or US Customary.

Design Tire Load - Design load per tire.

Design Tire Pressure - Design tire contact pressure.

Dual Spacing - Center to center distance between dual tires.

Fatigue Shift Factor for New AC - Shift factor for the new AC that modifies the laboratory fatigue equation to field fatigue conditions.

Fatigue Shift Factor for Old AC - Shift factor for the old AC that modifies the laboratory fatigue equation to field fatigue conditions.

Seasonal Variation Coarse Grained - Reduction factor for moduli values for coarse grained material. Unity means no reduction. Material types 1 or 3 (in Pavement Data) uses these values.

Seasonal Variation Fine Grained - Reduction factor for moduli values for fine grained material. Unity means no reduction. Material types 2 or 4 (in Pavement Data) uses these values.

Seasonal Variation Traffic - Reduction factor for traffic values. Total traffic volume is distributed according to the above fractions for each season.

Seasonal Mean Temperature - Seasonal mean air temperature used in adjusting the old AC and the new AC (overlay) moduli for the temperature change. The moduli values specified in the pavement data corresponds to standard temperature.

Seasonal Period - Number of months in each period.

1.4.4 PREPARE TRAFFIC DATA

1.4.4.1 File

Open - Open an existing TRAFFIC DATA File.

Save - Save the current TRAFFIC DATA File under the same name.

Save As - Save the current TRAFFIC DATA File under a different name.

Exit - Exit general data entry. Does not prompt for saving.

1.4.4.2 Help

Contents – Contains descriptions of the various program menus and entry requirements for program operation. The help screen is derived from the field descriptions contained in this User's Guide.

Search for Help on… - Typical Windows format for searching for key program descriptions.

1.4.4.3 Traffic Data

Title - Any descriptive text for identification purposes.

Units - Units of measurement and output, either Metric or US Customary.

Traffic Data Option - Select one of three options for entering traffic data.

80 kN ESALs for Design Period

Traffic data is to be specified with the total number of 80 kN (18,000 lb) equivalent single axle loads for the design period.

80 kN ESALs (18 k ESALs) for Design Period - 80 kN (18,000 lb) equivalent single axle loads for the design period.

Lane Distribution Factor (decimal) - Decimal of the total one-way ESALs in the design lane. This is a function of the number of lanes in each direction and can range from a high of 1.0 to a low of about 0.5. AASHTO recommends the following:

Number of Lanes (one-way)	Lane Distribution Factor
1	1.00
2	0.80 - 1.00
3	0.60 - 0.80
4 or more	0.50 - 0.75

80 kN ESALs per Year

Traffic data is to be specified with the total number of 80 kN (18,000 lb) equivalent single axle loads per year.

80 kN ESALs (18 k ESALs) for Design Period - 80 kN (18,000 lb) equivalent single axle loads for the design period.

Design Period (years) - Design period in number of years.

Annual Growth (%) - Annual traffic growth rate in percentage.

Lane Distribution Factor (decimal) - Decimal of the total one-way ESALs in the design lane. This is a function of the number of lanes in each direction and can range from a high of 1.0 to a low of about 0.5. AASHTO recommends the following:

Number of Lanes (one-way)	Lane Distribution Factor
1	1.00
2	0.80 - 1.00
3	0.60 - 0.80
4 or more	0.50 - 0.75

Average Daily Traffic

Traffic data is to be specified by the average daily traffic.

Average Daily Traffic (one-way) - Average daily traffic (one-way)

Truck Percentage - Truck traffic as a percentage of the average daily traffic.

Truck Factor - Truck factor for converting truck traffic into 80 kN ESALs (18 k ESALs).

Design Period (years) - Design period in number of years.

Annual Growth (%) - Annual growth rate of traffic (percentage).

Lane Distribution Factor (decimal) - Decimal of the total one-way ESALs in the design lane. This is a function of the number of lanes in each direction and can range from a high of 1.0 to a low of about 0.5. AASHTO recommends the following:

Number of Lanes (one-way)	Lane Distribution Factor
1	1.00
2	0.80 - 1.00
3	0.60 - 0.80
4 or more	0.50 - 0.75

1.4.5 PREPARE PAVEMENT DATA

1.4.5.1 File

Open - Open an existing PAVEMENT DATA File.

Save - Save the current PAVEMENT DATA File under the same name.

Save As - Save the current PAVEMENT DATA File under a different name.

Exit - Exit general data entry. Does not prompt for saving.

1.4.5.2 Help

Contents – Contains descriptions of the various program menus and entry requirements for program operation. The help screen is derived from the field descriptions contained in this User's Guide.

Search for Help on… - Typical Windows format for searching for key program descriptions.

1.4.5.3 Pavement Data

Route - Route name for identification purposes.

Units - Units of measurement and output, either in Metric or US Customary.

Overlay Data

Station/Milepost - Station or milepost, a maximum of ten characters.

Overlay AC Modulus - Modulus of the AC overlay material taken at the standard temperature

Poisson's Ratio - Poisson's ration of the AC overlay material.

Initial Overlay Thickness - Beginning overlay thickness. The program increases the initial overlay thickness by multiples of the Overlay Thickness Increment until the fatigue or rutting damage levels are less than one for the design traffic. The initial overlay thickness must be greater than 0 cm (0 inches).

Overlay Thickness Increment - Thickness by which the program increases the overlay depth until the fatigue and rutting damage levels are less than one for the design traffic.

Station/Milepost - Station or milepost, a maximum of ten characters.

Existing Pavement Data

No of Layers - Total number of layers, excluding the overlay layer. The maximum number of layers is limited to five, including the stiff layer.

Layer Information

Layer ID - Identifies whether the moduli of this layer is stress sensitive.

0 - Is an AC Material (Moduli is stress insensitive)
1 - Coarse Grained Material (Moduli varies with bulk stress stress)
    E = Multiplier * (Bulk Stress/Atmospheric Pressure) ^ Power
2 - Fine Grained Material (Moduli varies with deviator stress)
    E = Multiplier * (Deviator Stress/Atmospheric Pressure) ^ Power
3 - Coarse Grained Material (Moduli stress insensitive), but coarse grained seasonal variation applies

4 - Fine Grained Material (Moduli stress sensitive), but fine grained seasonal variation applies
5 - The specified layer modulus is used for all seasons without any corrections for Temperature, Stress Sensitivity, or Seasonal Variation.

Where Atmospheric Pressure is in the same unit as the stresses (14.696 psi or 101.4 kPa). Bulk Stress and Deviator Stress include static (overburden) stresses. The stresses used are calculated at the center of the Dual Tire location and at the bottom of the first layer, at the top of last layer, and at the middle of intermediate layers.

Note: It was customary to use the following form of the equation to describe stress sensitive moduli:

$E = \text{Multiplier} \times (\text{Bulk Stress})^{\text{Power}}$ (for Coarse Grained)

$E = \text{Multiplier} \times (\text{Deviator Stress})^{\text{Power}}$ (for Fine Grained)

The new coefficients are related to these coefficients by the following relationship:

Power New = Power Old

$\text{Multiplier New} = \text{Multiplier Old} \times (\text{Atmospheric Pressure})^{\text{Power Old}}$

Example: The following equation:

$E = 8500 \times (\text{Bulk Stress})^{0.375}$

would be equivalent to:

$E = 8500 \times (14.696)^{0.375} \times (\text{Bulk Stress/Atmospheric Pressure})^{0.375}$

$= 23287 \times (\text{Bulk Stress/Atmospheric Pressure})^{0.375}$

Poisson's Ratio - Enter the Poisson's ratio of this layer.

Thickness - Enter the thickness of this layer (cm or inches).

Modulus - Modulus of this layer. If this layer is stress sensitive, this will be used as the initial modulus and the program will compute a stress compatible modulus iteratively. If the material is AC (or asphalt stabilized), the required input modulus must be taken at the standard temperature.

Multiplier - If this layer is stress sensitive, use K1 or K3 regression coefficients.

Power - If this layer is stress sensitive, use K2 or K4 regression coefficients.

Max. Iteration - If any of the layers are stress sensitive, the maximum number of iterations allowed in obtaining the stress compatible moduli. A value of five is typical.

Modulus Tol. (%) - If any of the layers are stress sensitive, the modulus percentage tolerance in successive iterations. A value of 1.0 is typical.

Add Station - Add another station to be analyzed.

Delete Station - Delete the current station.

Unit Weight - Unit weight of the materials of the pavement layers.

Open - Open an existing PAVEMENT DATA File.

Save - Save the current PAVEMENT DATA File under the same name.

Save As - Save the current PAVEMENT DATA File under a different name.

Exit - Exit the Pavement Data Entry screen. Does not prompt for saving.

1.4.6 PRINT/VIEW RESULTS

This menu item allows the user to select the Output File Name to be either reviewed on the screen or printed to the default Windows printer.

Options – standard Windows protocols are used for viewing various pages, zoom, selecting font style for screen view and printing, printing and exiting print screen.

1.4.6 MODIFY STANDARD VALUES

The Standard Temperature and Fatigue and Rutting Equation coefficients can be changed using this menu item. These values are saved in a file called EVERPAVE.STD in the same directory as the Everpave © Programs files. These values need not be modified for each run but only when there is a need to change the old values. Please take extra care in reviewing the form of the equations listed below while determining the coefficients. The form of the equations might be slightly different from what you might have been using.

Standard Temperature – temperature correction is applied to the asphalt concrete moduli according to the following equation:

$$E_T = 10^{0.000147362(T_s^2 - T^2)} E_{T_s}$$

where,

T_s = Standard Temperature (°F)
T = Pavement Temperature (°F)
E_{T_s} = Asphalt Concrete Moduli at the Standard Temperature
E_T = Asphalt Concrete Moduli at the Pavement Temperature

The above regression equation is based on the results of various research projects which determined the asphalt concrete moduli at various laboratory testing temperatures.

Fatigue Equation Constants – the fatigue equation used in this program has the following format:

$$N_f = SF\left[a\,\varepsilon_t^{b}\left(\frac{E_{AC}}{\text{AtmosphericPressure}}\right)^{c}\right]$$

or

$$\log N_f = \log SF + \log a + b\log \varepsilon_t + c\log\left(\frac{E_{AC}}{\text{AtmosphericPrssure}}\right)$$

where,

N_f = Loads to failure in fatigue, number of loads for pavement to reach 10 percent alligator cracking
SF = Shift Factor
ε_t = Tangential tensile strain at the bottom of the asphalt concrete layer (in microns, 10^{-6})
E_{AC} = Asphalt concrete moduli
a = Constant
b = Exponent for strain
c = Exponent for moduli

The b and c coefficients are negative and the sign should be included in entering their values. Atmospheric Pressure is in the same unit as the stresses (14.696 psi or 101.4 kPa).

The default values for a, b, and c are 2.428E+16, -3.291, and -0.854, respectively (Reference: C. L. Monismith and J. A. Epps, Asphalt Mixture Behavior in Repeated Flexure, Institute of Transportation and Traffic Engineering, University of California, Berkeley, California, 1969) from the original equation:

$$\log N_f = 14.82 - 3.291 \log \varepsilon_t - 0.854 \log\left(\frac{E_{AC}}{1000}\right)$$

Suggested values for the shift factor are as follows:

Shift Factor	Comment
4	AC thickness is greater than 200 mm (8 inches)
7	AC thickness ranges between 100 and 200 mm (4 and 8 inches)
10	AC thickness is less than 100 mm (4 inches)

Rutting Equation Constants – the rutting equation used in the program has the following format:

$$Nr = a\,\varepsilon_v^{\,b}$$

or

$$\log Nr = \log a + b \log \varepsilon_v$$

where,

Nr = Loads to failure in rutting, number of loads for subgrade rutting to reach 13 mm (1/2 inch)
ε_v = Vertical compressive strain at the top of the subgrade (in microns, 10^{-6})
a = Constant
b = Exponent for Strain

The coefficients a and b are negative and the sign should be included when entering their values into the equation.

The default values for a and b and are 1.077E+18 and -4.4843, respectively (Reference: J. F. Shook, F. N. Finn, M. W. Mitczak, and C. L. Monismith, Thickness Design of Asphalt Pavements The Asphalt Institute Method, Proceedings, Vol. 1, Fifth International Conference on the Structural Design of Asphalt Pavements, The Netherlands, 1982, pp. 17-44)

1.4.7 EXIT

Exits the program and returns to Windows.

1.5 EXECUTION OF THE PROGRAM

As a general note, any time you save a file in Everpave ©, use the same extension as designated by the program. The program calls the required files according to their extension. It will save the user time and key strokes if the program extension protocols are followed.

After the user has started Windows, the program can be initiated by double clicking onto the Everpave© icon. The screen as shown in Figure 3.1 will be displayed.

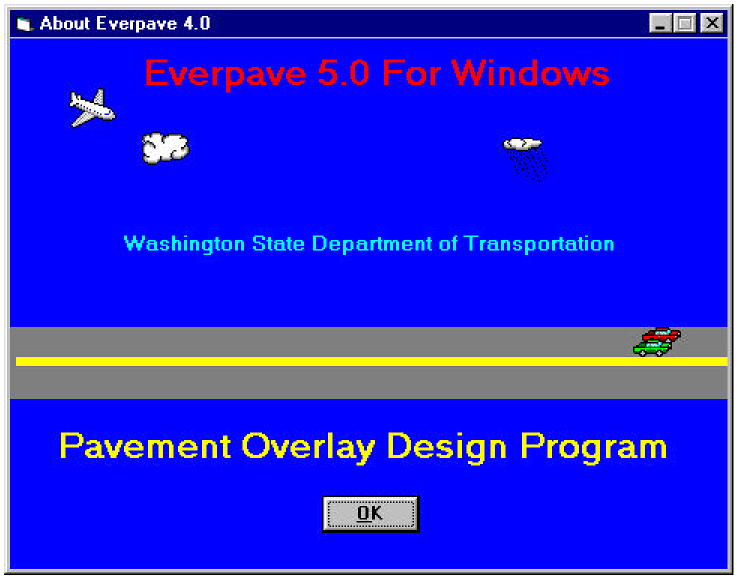

Figure 3.1. About Everpave© Screen

Press the **OK** button and the screen as shown in Figure 3.2 will be displayed.

Figure 3.2. Everpave© Main Screen

To begin the pavement overlay process, the GENERAL DATA File, the PAVEMENT DATA File, and the TRAFFIC DATA File must first be created. To create the GENERAL DATA File, select **File** and then select **Prepare General Data**. The screen as shown in Figure 3.3 will be displayed.

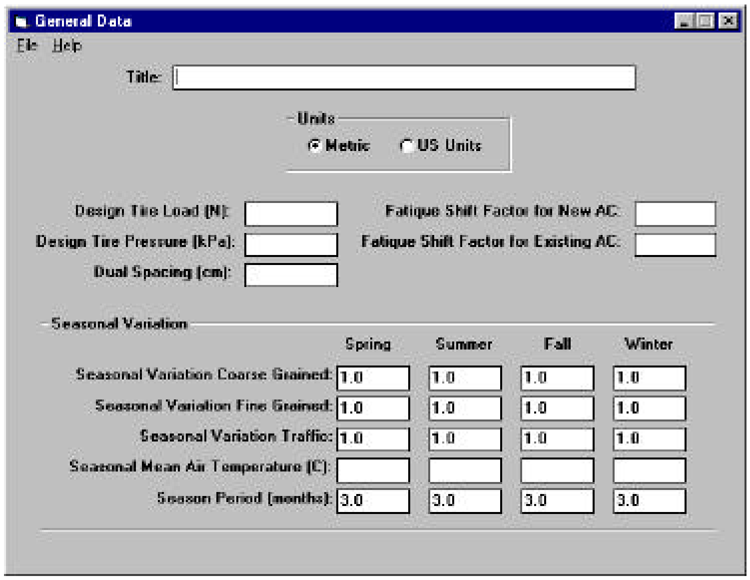

Figure 3.3. General Data Screen

At this screen the user must enter the following information:

- Title of the project,
- Units of measurement
- Design tire load (kN or lbf) and design tire pressure (kPa or psi)
- Center to center spacing of the dual tires (cm or inches). If the pavement is being analyzed using single tires enter a spacing of 0 mm (inches),
- Fatigue shift factor of the new and old AC,
- Seasonal variation of the coarse and fine grained soils and traffic,
- Seasonal mean air temperature (°C or °F) and the number of months in each seasonal period.

After all the data has been entered, the data must be saved as a file. Select **File,** select **Save** and the program will prompt the user for the filename. After the GENERAL DATA File has been saved, select **File** and then select **Exit** to return to the Main Screen.

To enter the traffic data, select File and then select Prepare Traffic Data. The screen as shown in Figure 3.4 will be displayed.

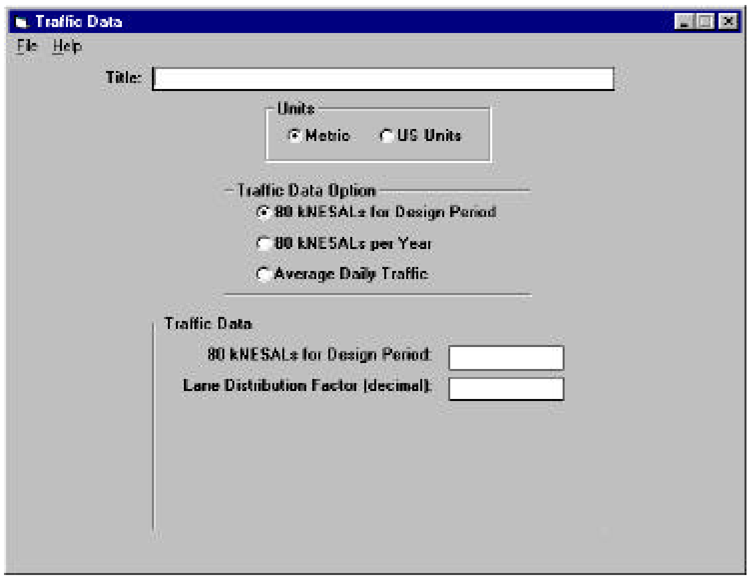

Figure 3.4. Traffic Data Screen (80 kN ESAL's for Design Period)

At this screen the user must enter the title description of the project, the units of measure, the traffic data option and the necessary traffic data. Three options are available for determining the traffic data: 80 kN ESAL's for Design Period (as shown in Figure 3.4), 80 kN ESAL's per year (as shown in Figure 3.5) and Average Daily Traffic (as shown in Figure 3.6).

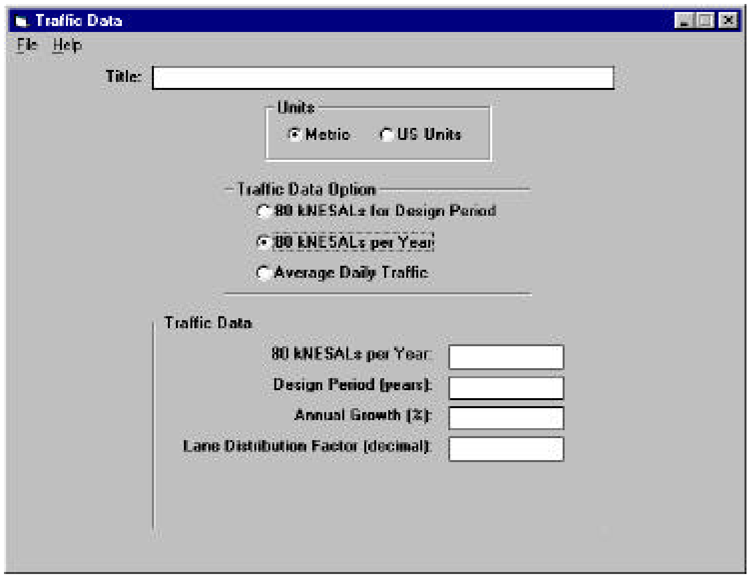

Figure 3.5. Traffic Data Screen (80 kN ESAL's for Design Period)

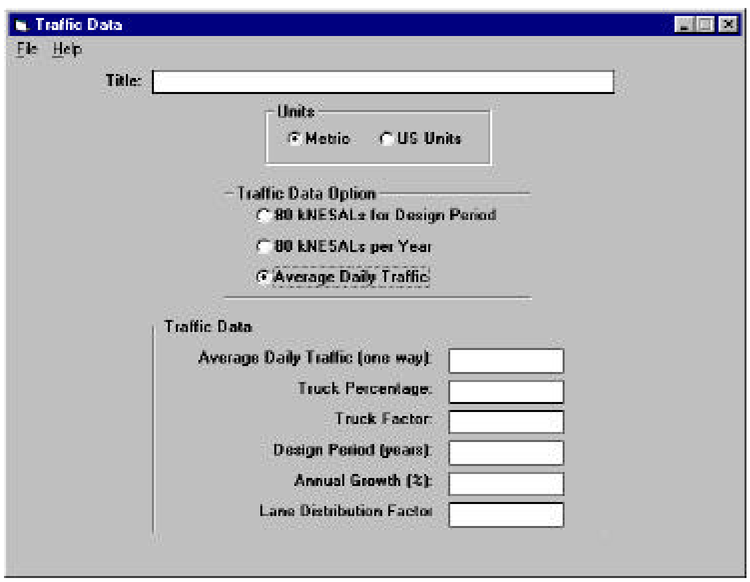

Figure 3.6. Traffic Data Screen (Average Daily Traffic)

Upon completion of data entry, the user must save the data as a file. Select **File**, select **Save** and the user will be prompted for the filename. To return to the Main screen select **File** and then select **Exit**.

To enter the pavement data, select **File** and then select **Prepare Pavement Data**. The screen as shown in Figure 3.5 will be displayed.

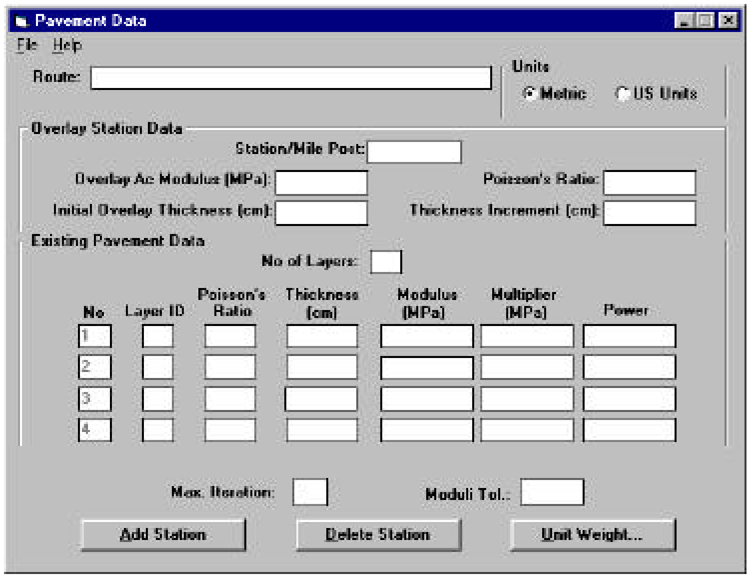

Figure 3.5. Pavement Data Screen

At this screen the user must enter the following:

- Description of the Route,
- Units of measure (metric or US Customary),
- Station/milepost location
- Modulus of the AC overlay (MPa or ksi)
- Poisson's ratio of the AC overly
- Initial overlay thickness (cm or inches)
- Thickness increment (cm or inches)
- Number of pavement layers
- For the existing pavement structure - layer number, layer identification number (identifies stress sensitivity), Poisson's ratio, thickness (cm or inches), and layer modulus (MPa or ksi)

The user is also capable of modifying the unit weight for each of the layers entered. To modify the unit weights, select **Unit Weight** and make the necessary changes. Once modifications have been made, select **Exit** to return to the Pavement Data Screen.

Once all data has been entered, the data must be saved to a file. Select **File**, select **Save** and the user will be promoted for the filename. To return to the Main screen, select **File** and then select **Exit**.

To analyze the data, select **Analyze Pavement**. The program will prompt the user for the name of the GENERAL DATA File, the TRAFFIC DATA File, and the PAVEMENT DATA File to be used. The program will then ask the user if the filename of the Output File is OK, select **OK** or modify the output filename.

To view the results select **File** and then select **Print/View Results**. The up and down arrows or the page up and page down keys can be used to view the data. To print the data on the Windows default printer, select **Options** and then select **Print**. To exit this screen, select **Options** and then select **Exit**.

To exit the Everpave© program, select **File** and then select **Exit**.

1.6 EXAMPLE

General Data:

Design Tire Load = 20 000 N
Tire Pressure = 700 kPa
Dual Spacing = 35 cm
Fatigue Shift Factor (new and old AC) = 10

Season Variation:

	Spring	Summer	Fall	Winter
Coarse Grained	.650	1.000	.900	1.100
Fine Grained	.950	1.000	.900	1.100
Traffic Volume	1.000	1.000	1.000	1.000
Mean Air Temp (C)	7.5	18	7.5	-2.8
Period (month)	4	4	3	1

Traffic Data

80 kN ESALs for Design Period = 1 700 000
Lane Distribution Factor (decimal) = 1.00

Pavement Data

Overlay AC modulus = 2 700 MPa
Poisson's Ratio for AC overlay = 0.35
Initial Overlay Thickness = 2.5 cm
Thickness Increment = 1 cm

Existing Pavement Data:

Number of layers = 3

Number	Layer ID	Poisson's Ratio	Thickness (cm)	Modulus (MPa)
1	0	0.35	10	2313
2	3	0.40	40	131
3	4	0.45		70

1.6.1 OVERLAY THICKNESS DESIGN RESULTS

Layered Elastic Analysis by Everpave© 5.0

General Data: Example

Design Tire Load (N): 20000.0	Tire Pressure (kPa): 700.00	Dual Tire Spacing (cm): 35.0
Fatigue Shift Factor:	New AC: 10.00	Old AC: 10.00

Seasonal Variation:	Spring	Summer	Fall	Winter
Coarse Grained:	.650	1.000	.900	1.100
Fine Grained:	.950	1.000	.900	1.100
Traffic Volume:	1.000	1.000	1.000	1.000
Mean Air Temp (C):	7.5	18.0	7.5	-2.8
Period (month):	4.0	4.0	3.0	1.0

Traffic Data: Example
80 kN ESALs for Design Period:1700000.
Lane Distribution Factor (decimal): 1.00
Total Design Traffic (80 kN ESALs): 1700000.

Route: Test

Station: 1.00

Layer	Poisson's Ratio	Thickness (cm)	Moduli (1) (MPa)
1	.35	2.5	2700.00
2	.35	10.000	2313.00
3	.40	40.000	131.00
4	.45		70.00

Pavement Moduli Used (MPa)

Layer	Material	Spring	Summer	Fall	Winter
1	A.C.	7896.33	3261.31	7896.33	14172.09
2	A.C.	6764.52	2793.86	6764.52	12140.76
3	C.G.	85.15	131.00	117.90	144.10
4	F.G.	66.50	70.00	63.00	77.00

Critical Values

Season:	Spring	Summer	Fall	Winter
Tensile Strain in New AC:	5.62	21.88	5.71	2.37
Tensile Strain in Old AC:	121.70	203.64	115.55	71.37
Compressive Strain in Subgrade;	215.85	291.83	226.40	156.94
Max. Surface Deflection (microns):	390.53	433.61	380.08	282.22

Damage Levels

Fatigue Damage on New A.C.: .000
Fatigue Damage on Old A.C.: .956
Rutting Damage on Subgrade: .090
Overlay Thickness (cm): 6.50

SECTION 3.0
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SECTION 4.0

CASE STUDY NO. 1

SR 395 MP 207.80 to MP 212.67
Chewelah to Iron Mountain Road

This SECTION will describe a WSDOT rehabilitation project which will show each of the overlay design procedures used in the determination of the overlay thickness.

1. INTRODUCTION

This case study comes from a section of State Route (SR) 395 which begins at the community of Chewelah, Washington (MP 207.81) and proceeds north to Iron Mountain Road (MP 212.67). The 1994 pavement condition survey for this project indicated 5 to 15 percent of low to medium severity alligator cracking and 30 percent medium to high severity longitudinal cracking. According to the WSPMS, the current PSC on this project is 58 and is projected to reach a program level PSC of 50 in 1995; however, the PSC ranges from 0 to 80 for specific locations (refer to photos shown in Appendix 4.1). In addition to a structural overlay, this project also proposes to widen the roadway by 0.6 m to provide for a 3.7 m lane and 2.4 m shoulder in each direction. This project is scheduled for construction in 1995.

The Stevens County Soils Survey shows the project site is composed of varying morphology. The predominate soil is the Hodgson Silt Loam (ML). This soil is very deep, moderately well drained and is located in undulating terraces. From February to April there is typically a perched water table at depths of 600 to 900 mm. Related engineering properties are: moderately slow permeability, low to moderate shrink swell potential, and moderate susceptibility to frost action. Typical base material, retrieved by augering, is silty sandy gravel or sandy gravel and varies from 305 to 457 mm in depth.

This project was originally constructed in 1945 with a 20 mm bituminous surface treatment placed over 80 mm of crushed surfacing top course (crushed stone base) and from 230 to 460 mm of select roadway borrow. Construction during 1948 placed an additional 20 mm of bituminous surface treatment. Projects after 1948 rehabilitated different sections within the current project limits. A summary of AC core depths, base thickness and core description are listed in Table 4.1. The base thickness was taken from the WSPMS.

Table 4.1. Summary of Roadway Surfacing Depths

Core Location	Depth AC (mm)	Depth Base (mm)	Comments
207.85	134	457	Core taken at a crack, crack is full depth
208.00	152	457	Core taken at a crack, core not intact
208.50	119	305	Core taken at a crack, crack is full depth
209.00	116	305	Very fatigued, core broke into several pieces
209.05	107	305	Fatigued area, crack is full depth
209.40	149	335	Core taken at a crack, crack is full depth
209.80	165	396	AC core intact
210.00	113	366	Fatigue in both wheel paths, crack is full depth
210.50	98	366	Core taken at a crack, crack is full depth
211.00	229	366	Core broke into several pieces
211.50	283	366	AC core intact
212.00	299	366	AC core intact
212.50	229	366	Top 183 mm in good condition

Current traffic volumes are around 5,500 vehicles per day (two way) with 13 percent trucks. The design period is 15 years and the associated estimated ESALs are 2,896,000.

Table 4.2 summarizes the deflection data that was collected on this project on April 14, 1993. Though the project was over 7.8 km long and FWD testing was performed every 75 m, only the FWD data that corresponds to a core location is being evaluated as part of this case study. Knowing the AC layer thickness to within 6 mm is essential in assuring a more accurate prediction of layer moduli in the backcalculation procedure. The average pavement temperature at the time the FWD data was collected was 8°C to 10°C. The timing of the survey was about 1.5 to 2 months after the spring thaw in this area. The normalized (40 kN) deflections, Area value (see Volume 2, SECTION 7.0, Paragraph 3.2.2) and the subgrade modulus using the normalized deflections, as determined by Equation 4.1 below (see Volume 2, SECTION 7, Paragraph 1.8.3.2), are also shown in Table 4.2.

$$M_R = \frac{(40\ \text{kN})(0.2892)(1000)^2}{(610\ \text{mm})(\text{Defl}_{610})} \tag{4.1}$$

Table 4.2. FWD Deflections, Area Value and Subgrade Modulus

Core Location	Load (N)	Deflections (μm) D0	D203	D305	D610	D915	D1220	Area Value (mm)	M_R (MPa)
207.85	75 352	795	665	589	350	231	169		
	53 762	615	516	460	263	173	126		
	41 909	494	416	370	206	134	101		
	27657	335	286	252	130	86	72		
Normalized Values		**467**	**394**	**350**	**193**	**127**	**97**	**540**	**99**
208.00	75 563	687	547	472	286	186	134		
	53 692	540	431	371	220	141	101		
	41 839	445	354	304	178	113	82		
	27 516	313	248	211	118	73	52		
Normalized Values		**421**	**336**	**288**	**167**	**106**	**76**	**512**	**114**
208.50	74 858	379	302	260	150	81	58		
	54 468	296	236	202	114	54	44		
	42 403	244	194	166	92	46	33		
	28 010	171	136	114	61	32	22		
Normalized Values		**229**	**182**	**155**	**86**	**43**	**32**	**494**	**222**
209.00	72 530	1505	1234	1080	541	242	130		
	52 210	1172	953	827	396	170	91		
	41 133	938	757	651	299	126	68		
	27 375	635	505	426	185	77	44		
Normalized Values		**902**	**728**	**625**	**290**	**123**	**67**	**475**	**66**
209.05	71 048	1426	1140	969	556	344	236		
	51 293	1118	894	751	420	254	174		
	40 427	905	718	597	321	191	128		
	26 669	644	488	392	190	118	71		
Normalized Values		**893**	**702**	**581**	**311**	**189**	**125**	**481**	**61**
209.40	71 189	1597	1316	1106	631	377	244		
	51 646	1268	1044	871	491	293	189		
	40 498	1020	846	697	382	227	145		
	29 952	725	581	466	241	145	94		
Normalized Values		**1002**	**821**	**675**	**369**	**220**	**142**	**496**	**51**
209.80	76 763	677	548	475	286	182	126		
	54 397	528	429	371	220	137	94		
	42 403	426	347	298	171	107	72		
	27 869	298	240	203	111	69	44		
Normalized Values		**402**	**326**	**280**	**160**	**100**	**67**	**516**	**119**
210.00	74 364	914	742	639	426	285	197		
	53 480	706	574	490	323	213	145		
	41 909	567	457	388	250	162	111		
	27 446	385	307	256	160	101	70		
Normalized Values		**538**	**434**	**367**	**236**	**154**	**105**	**529**	**80**

Table 4.2. FWD Deflections, Area Value and Subgrade Modulus, continued...

Core Location	Load (N)	Deflections (µm) D0	D203	D305	D610	D915	D1220	Area Value (mm)	M_R (MPa)
210.50	76 339	568	488	423	265	175	120		
	54 327	441	380	329	201	128	89		
	41 980	355	306	264	159	100	68		
	27 446	244	210	179	104	63	42		
Normalized Values		**336**	**289**	**249**	**149**	**93**	**64**	**547**	**128**
211.00	76 410	344	300	278	204	154	116		
	54 820	264	228	209	155	116	85		
	42 826	203	181	166	122	90	66		
	28 433	144	121	109	80	58	43		
Normalized Values		**194**	**168**	**153**	**113**	**83**	**61**	**626**	**168**
211.50	77 680	320	266	239	169	119	82		
	56 161	234	195	175	123	87	59		
	43 955	179	150	134	93	65	44		
	28 857	113	94	83	57	40	27		
Normalized Values		**162**	**135**	**121**	**84**	**59**	**40**	**584**	**226**
212.00	78 809	570	519	483	362	269	199		
	56 161	431	392	364	272	201	149		
	44 590	340	310	287	215	158	118		
	29 280	225	204	188	139	103	76		
Normalized Values		**306**	**278**	**257**	**192**	**142**	**105**	**660**	**99**
212.50	80 925	495	441	407	316	242	177		
	57 502	382	337	310	241	183	135		
	45 790	296	267	244	191	144	102		
	30 197	206	178	161	125	93	64		
Normalized Values		**266**	**235**	**214**	**167**	**125**	**89**	**650**	**114**

As shown in Table 4.2, the average normalized D0 deflection ranges from 138 µm to 1 002 µm and average 466 µm with a standard deviation of 290 µm. Deflections less than about 760 µm are considered normal.

The Area values shown in Table 4.2 do not suggest extremely weak AC, such as a loss of stiffness due to stripping. For example, typical theoretical Area values for various uncracked AC thicknesses are:

	Approximate Area Parameter (mm)	
AC Thickness (mm)	Normal Stiffness	Low Stiffness
50	430	410
75	490	450
100	540	490
125	590	530
150	620	550
175	650	570
200	670	590
225	690	610
250	700	620

A quick, approximate check of the pavement structure is to compare the actual Area value to see if it falls within the range (normal to low stiffness), above this range (above normal stiffness) or below this range (below normal stiffness). This comparison follows:

Core Location	AC Thickness (mm)	Actual Area (mm)	Above, Below or Within Range
207.85	134	540	Below
208.00	152	512	Below
208.50	119	494	Below
209.00	116	475	Below
209.05	107	481	Within
209.40	149	496	Below
209.80	165	516	Below
210.00	119	529	Below
210.50	98	547	Above
211.00	229	626	Within
211.50	283	-	-
212.00	299	-	-
212.50	229	650	Within

The above basically suggests MP's 207.85 to 210.00 will likely need a structural overlay. MP's 210.50 to MP 212.50 are in better structural condition suggesting the overlay requirement will be minimal.

The elastic modulus values of the subgrade range from 51 MPa to 275 MPa with an average of 108 MPa and a standard deviation of 63 MPa. On the average, a subgrade modulus of 100 MPa is typical for Washington state. This fairly large variation in stiffness is most likely due to variation in soil moisture and the proximity of underlying rock, more than actual soil or deposition changes along the roadway.

There are two fairly distinct sections occurring within the project limits. The roadway from MP 207.80 to MP 210.55 is in fair to poor condition with low to medium severity longitudinal and alligator cracking. From MP 210.55 to MP 212.67 the roadway is generally in good condition with only a few locations of low severity longitudinal and alligator cracking. Figure 4.1 graphically shows how the normalized center deflection, normalized Area value and subgrade modulus varies throughout the projects length. Figure 4.1 was created from an in-house computer program and this program has yet to be converted to metric units. Therefore, Figure 4.1 shows the center deflection in mils, the Area value in inches and the subgrade modulus in ksi.

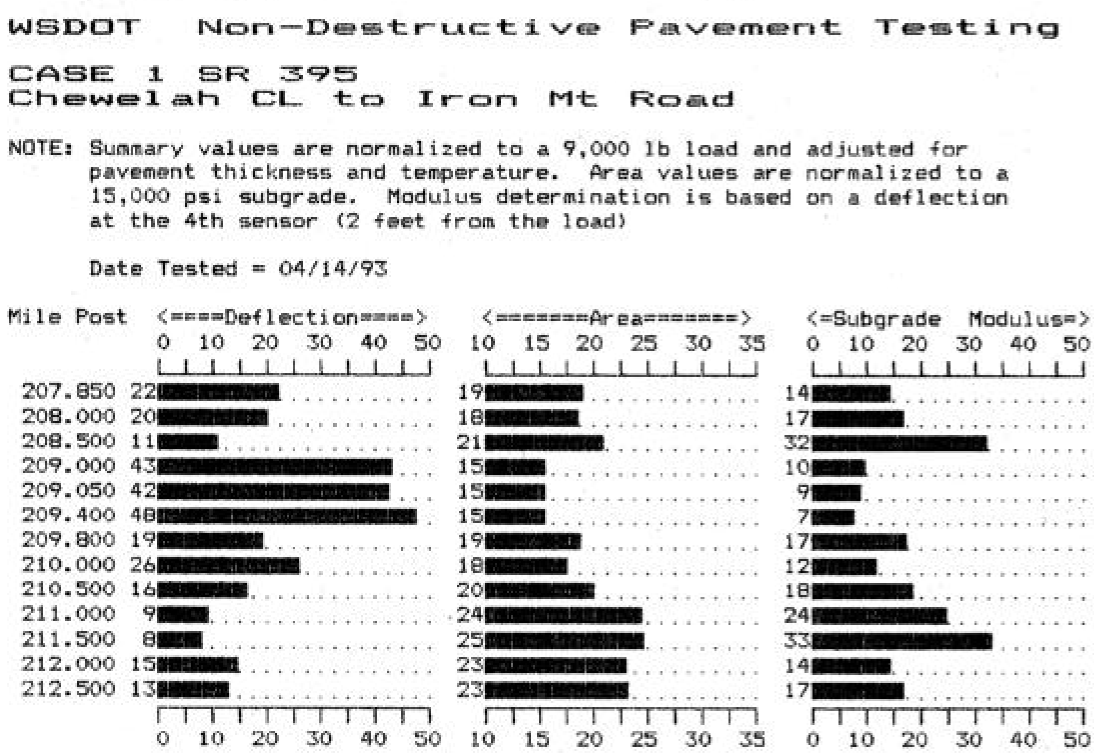

Figure 4.1. Normalized Center Deflection, Area Value, and Subgrade Modulus

2. OVERLAY DESIGN PROCEDURES

This SECTION describes three overlay design procedures that are currently used by WSDOT: 1) WSPMS SCOPER, 2) WSDOT Empirical-Mechanistic Overlay Design, and 3) AASHTO Overlay Design Procedure. The three procedures can be used as design checks as will be more fully described later.

2.1 WSPMS SCOPER OVERLAY DESIGN PROCEDURES

WSPMS SCOPER is partially based on the Asphalt Institutes Component Analysis procedure (see Volume 2, SECTION 7.0, Paragraph 1.3). Specific modifications made by WSDOT can be found in "Washington State Pavement Management - A 1993 Update", Research Report WA-RD 274.1, Washington State Department of Transportation, Olympia Washington, 1993.

The WSPMS SCOPER uses a component analysis approach that essentially requires the total pavement structure to be developed as a new design for the specified service conditions and then compared to the existing pavement structure (taking into account both pavement condition, type, and thickness of the pavement layers). The component design process requires substantial engineering judgment. This judgment is mainly associated with the selection of "weighting factors" or "conversion factors" to use in evaluating the structural adequacy of the existing pavement layers. The SCOPER design approach uses relationships between subgrade strength, pavement structure, and traffic to determine the overlay thickness.

2.1.1. EXAMPLE OF CALCULATIONS

Layer coefficients and ESAL's were determined using the WSPMS. The subgrade modulus as determined from the FWD analysis as shown in Table 4.2 was used in this analysis. Refer to Table 4.3 for SCOPER overlay design results. To illustrate this process, MP 207.85 will be used as an example.

MP 207.85

(134 mm AC)(0.30)	=	40 mm
(457 mm Base)(0.30)	=	137 mm
Effective Thickness	=	177 mm

M_R = 99 MPa
ESAL = 2 896 000

Refer to Design Thickness charts in Asphalt Institutes MS-1 Manual or Volume 2, SECTION 7.0, Paragraph 1.3.

Design Thickness	=	219 mm
Effective Thickness	=	177 mm
Overlay Thickness	=	42 mm

Table 4.3. WSPMS SCOPER Overlay Design Procedure

Core Locations	Depths AC (mm)	Depths Base (mm)	Layer Coefficients AC	Layer Coefficients Base	Subgrade Modulus (MPa)	Thickness (mm) Design	Thickness (mm) Effective	Thickness (mm) Overlay
207.85	134	457	0.30[1]	0.30	99	248	177	71
208.00	152	457	0.30	0.30	114	238	183	55
208.50	119	305	0.30	0.30	222	184	128	56
209.00	116	305	0.30	0.30	66	274	127	147
209.05	107	305	0.30	0.30	61	279	124	155
209.40	149	335	0.30	0.30	51	289	146	143
209.80	165	396	0.30	0.30	119	234	169	65
210.00	113	366	0.30	0.30	80	246	144	118
210.50	98	366	0.30	0.30	128	229	139	90
211.00	229	366	0.82[2]	0.30	168	208	298	0
211.50	283	366	0.82	0.30	226	183	342	0
212.00	299	366	0.82	0.30	99	248	355	0
212.50	229	366	0.82	0.30	114	238	298	0

[1] AC “C” value based on a PSC = 0
[2] AC “C” value based on a PSC = 74

2.2 WSDOT MECHANISTIC-EMPIRICAL OVERLAY DESIGN

2.2.1. EVERCALC©

Currently, when a pavement structure is analyzed using FWD data and a backcalculation procedure, it is recommended to vary the use and stiffness of the stiff layer. A stiff layer should be used when the underlying material is known to be saturated or if underlying rock or other very stiff deposits are known to exist (refer to Volume 2, SECTION 7.0, Paragraph 3.3.4). In most instances, the presence, the stiffness, and depth to stiff layer is not known. Therefore, it is advisable to use three backcalculation approaches with regard to a potential stiff layer: 1) no stiff layer, 2) a stiff layer at 345 MPa (50,000 psi), which indicates a moist or saturated layer, and 3) a stiff layer at 6 895 MPa (1,000,000 psi), which indicates a rock layer or stiff deposit.

2.2.1.1 Input Values

General Data

Number of layers	=	3 (no stiff layer)
		4 (stiff layer)

Units = Metric
Indicate whether or not a stiff layer option is to be used
Temperature correction to be applied
Temperature Measurement = Direct Method
Plate radius = 15 cm
Seed Moduli = User supplied

Sensor No.	1	2	3	4	5	6
Radial Offset (cm)	0	205	305	610	915	1220

Layer Information is shown in Table 4.4.

Table 4.4. Layer Characteristics Input Values

Layer	Description	Poisson's Ratio	Modulus (MPa) Initial	Minimum	Maximum
1	AC	0.35	2 758	689	13 790
2	Base	0.40	172	34	3 447
3	Subgrade	0.45	103	34	3 447
4*	Stiff layer (water)	0.35	345		
4*	Stiff layer (rock)	0.30	6 895		

* Denotes the use of a stiff layer.

Deflection Data

Refer to Volume 3, SECTION 2.0 for the necessary procedures for entering deflection data or for converting the raw FWD deflection file into EVERCALC.

Backcalculation Results

The backcalculated layer moduli, for all three cases (no stiff layer and stiff layers at 345 and 6 895 MPa) are shown in Table 4.5.

Table 4.5. Summary of EVERCALC Results

	No Stiff Layer					Depth to	Stiff Layer @ 345 Mpa					Stiff Layer @ 6895 Mpa				
Core Location	Eadj[1] (Mpa)	Eac[2] (Mpa)	Ebase (Mpa)	Esub (Mpa)	RMS	Stiff Layer (m)	Eadj (Mpa)	Eac (Mpa)	Ebase (Mpa)	Esub (Mpa)	RMS	Eadj (Mpa)	Eac (Mpa)	Ebase (Mpa)	Esub (Mpa)	RMS
207.85	1137	3640	115	82	3.09	4.96	**979** [3]	3134	**150**	70	4.12	929	2975	164	63	4.53
208.00	900	2881	121	101	0.70	4.05	**735**	2352	**168**	80	1.80	677	2167	191	68	2.52
208.50	3657	11706	115	250	3.39	1.55	**2535**	8114	**298**	154	5.37	1399	4480	761	63	10.73
209.00	610	1953	34	90	13.40	1.19	**1734** [4]	5551	**117**	34	24.56	2630	8417	34	34	41.88
209.05	1167	3736	41	59	2.04	2.50	**619**	1981	**128**	35	5.29	1274	4079	81	34	10.12
209.40	416	1331	34	52	2.00	2.17	**645**	2065	**34**	34	14.39	652	2087	34	34	21.76
209.80	976	3125	86	117	0.96	3.61	**781**	2500	**143**	89	1.60	691	2211	180	73	2.41
210.00	2048	6556	95	72	2.29	3.23	**1137**	3639	**200**	48	0.83	1000	3200	227	42	0.99
210.50	4868	17036	115	119	0.64	8.63	**4405**	15417	**143**	120	0.76	4154	14536	163	110	0.85
211.00	1879	6576	148	139	0.76	5.68	**1904**	6661	**196**	126	0.63	1796	6287	259	105	0.68
211.50	1317	4608	81	256	0.66	3.06	1272	4450	121	204	0.67	**1158**	4053	**268**	**110**	1.13
212.00	825	2887	34	97	2.08	7.97	876	3064	34	92	1.88	**895**	3131	**34**	**86**	1.86
212.50	1968	6886	36	122	1.23	5.13	1927	1927	66	91	0.97	**1836**	6427	**102**	**74**	0.86

[1] Eadj is Eac adjusted to a standard temperature of 25°C (77°F).

[2] Eac is the actual backcalculated modulus for the AC at the insitu field temperatures.

[3] Bold number indicate the moduli that were selected for input ontp EVERPAVE. Moduli are selected based on engineering judgment and low RMS.

[4] Due to the severity of distress at the location (refer to Appendix 4.1), the AC modulus was "fixed at 690 MPs and the base and subgrade moduli were re-evaluated in EVERCALC. The corresponding base and subgrade modulud are 117 and 34 Mpa, respectively

2.2.2. EVERPAVE©

Everpave© is a mechanistic-empirical overlay design procedure that was developed by WSDOT. The pavement analysis is accomplished by use of Everstress© (used as a subroutine, see Volume 3, SECTION 1.0), which can account for the stress sensitive characteristics of the unbound materials. Everpave© uses the material properties (modulus) of each pavement layer (e.g. AC, base and subgrade). traffic load repetitions and the environment (seasonal temperatures and moduli) to determine the appropriate overlay design thickness. The determination of the appropriate thickness is based on the two primary distresses found in flexible pavements in Washington State; rutting and fatigue cracking (see Volume 2, SECTION 7.0, Paragraph 1.6). The Everpave© program calculates the overlay thickness by comparing the pavement performance lives for fatigue and rutting with the projected design traffic volume (ESALs). When the minimum repetitions of the two failure criteria is greater than the traffic volume, the final overlay thickness is produced. Otherwise, the overlay thickness is increased by an incremental thickness and the analysis is repeated.

2.2.2.1 Input Values

General Input Data (see Volume 2, SECTION 7.0, Paragraph 1.6.4)

Tire Load	20 000 N
Tire Pressure	689 kPa
Shift factor for New AC	10
Shift factor for Existing AC	10
Dual Tire Spacing	35.6 cm

	Spring	Summer	Fall	Winter
Seasonal Variation				
Base Course	1.00	1.54	1.38	1.69
Subgrade	1.00	1.11	1.0	1.22
Traffic	1.00	1.00	1.00	1.00
Mean Air Temperature °C	7.6	18.1	7.5	-2.8
Season Period (months)	4	4	3	1

For mean air temperature refer to Volume 2, SECTION 7.0, Appendix 7.1, Table 1 and for seasonal periods (months) refer to Table 7.4, Volume 2, SECTION 7.0, Paragraph 1.6. The moduli ratios assume that the FWD deflection testing was performed during the critical spring period. Thus, the spring moduli ratios shown above were set to 1.0 (base and subgrade). The other seasonal moduli ratios were then adjusted accordingly (refer to Volume 2, SECTION 7.0, Table 7.4).

Pavement Data

Overlay AC Moduli	=	2 758 MPa
Poisson's ratio	=	0.35
Initial Overlay Thickness	=	0.5 cm
Thickness Increment	=	0.5 cm

Traffic Data

80 kN ESAL's for Design Period (15 years)	=	2 896 000
Lane Distribution Factor	=	1.00
Total Design ESAL's	=	2 896 000

The results of the Everpave© overlay analysis are presented in Table 4.6. As a reminder, the initial overlay thickness was established at 5 mm for this case study. Therefore, those locations that indicate a 5 mm overlay, are more likely based on the initial overlay thickness set by the user.

Table 4.6. Everpave© Overlay Thickness Results

Core Location	AC (cm)	Base (cm)	Selected Layer Moduli Eac (MPa)	Ebase (MPa)	Esub (MPa)	Everpave© Overlay (mm)
207.85	13.4	45.7	979	150	70	50
208.00	15.2	45.7	735	168	80	40
208.50	11.9	30.5	2535	298	154	10
209.00	11.6	30.5	690	117	34	95
209.05	10.7	30.5	619	128	35	100
209.40	14.9	33.5	645	34	34	110
209.80	16.5	39.6	781	143	89	35
210.00	11.3	36.6	1137	200	48	60
210.50	9.8	36.6	4405	143	120	35
211.00	22.9	36.6	1904	196	126	10
211.50	28.3	36.6	1158	268	110	10
212.00	29.9	36.6	895	34	86	10
212.50	22.9	36.6	1836	102	74	10

2.3 AASHTO - DARWin PAVEMENT DESIGN SYSTEM

DARWin is the computerized version of the pavement design models presented in AASHTO's "Guide for Design of Pavement Structures 1993." From the DARWin User's Guide, "In the AASHTO overlay design procedure, the structural capacity for future traffic (SC_f) and the effective structural capacity (SC_{eff}) of the existing pavement are calculated using one of up to four available methods. These structural capacities are then used to determine the required overlay structural capacity." For this case study, the non-destructive testing method will be used for overlay determination. DARWin uses the deflection data to backcalculate the subgrade modulus (M_R) and the effective pavement modulus (E_p). These values are then used to determine the structural numbers for the existing pavement and for future traffic volumes. The required overlay structural number is the difference between SC_f and SC_{eff}.

2.3.1. INPUT VALUES

18 k ESAL's	2 896 000
Initial Serviceability	4.5
Terminal Serviceability	3.0
Reliability Level (%)	50
Overall Standard Deviation	0.50
Overlay Layer Coefficient (a_{ol})	0.44

Calculated Overlay Structural Number (SN_{ol}) = Non-Destructive Method

Point-by-Point Backcalculation

FWD Load	9000 lbs
Resilient Modulus Correction Factor	0.5
Base Type	Granular

Mid-depth Pavement Temperature	50°F (MP 207.85 - MP 210.05)
	47°F (MP 210.05 - MP 212.67)

The normalized load (9000 lbs) and corresponding deflections are shown in Table 4.7. WSDOT uses a FWD sensor spacing of 0, 8, 12, 24, 36, and 48 inches. DARWin will accommodate deflection data collected at any deflection spacing and at any load level. The FWD sensor spacing was selected such that the deflection basin would be adequately identified. Typically, the pavement structural design is based on a legally loaded axle of 18,000 lbs (9000 lbs per one-half of the axle). Therefore, the normalized deflections at 9000 lbs are used in this procedure. Results of this analysis are shown in Table 4.8.

Table 4.7. Normalized Deflection Data

MP	Load (lbs)	$D_{at\ 0”}$ (mils)	$D_{at\ 8”}$ (mils)	$D_{at\ 12”}$ (mils)	$D_{at\ 24”}$ (mils)	$D_{at\ 36”}$ (mils)	$D_{at\ 48”}$ (mils)
207.85	9000	18.37	15.51	13.77	7.59	4.99	3.83
208.00	9000	16.59	13.21	11.32	6.56	4.16	2.98
208.50	9000	9.01	7.16	6.10	3.37	1.68	1.24
209.00	9000	35.51	28.65	24.62	11.40	4.84	2.65
209.05	9000	35.14	27.62	22.88	12.24	7.43	4.90
209.40	9000	39.46	32.33	26.59	14.54	8.68	5.58
209.80	9000	15.83	12.83	11.00	6.30	3.93	2.62
210.00	9000	21.18	17.07	14.45	9.31	6.05	4.15
210.50	9000	13.21	11.39	9.79	5.86	3.68	2.52
211.00	9000	7.63	6.61	6.02	4.45	3.28	2.41
211.50	9000	6.36	5.31	4.75	3.31	2.31	1.57
212.00	9000	12.05	10.95	10.13	7.55	5.58	4.14
212.50	9000	10.49	9.27	8.44	6.57	4.94	3.50

Table 4.8. AASHTO DARWin Overlay Thickness Results

Core Location	Pavement Depths AC (in)	Base (in)	Total (in)	SN for Future Traffic	Effective Existing Pavement SN	Calculated Overlay SN (SN_{ol})	Overlay Thickness (in)
207.85	5.3	18.0	23.3	3.72	3.78	0.00	0
208.00	6.0	18.0	24.0	3.46	3.96	0.00	0
208.50	4.7	12.0	16.7	2.70	3.56	0.00	0
209.00	4.6	12.0	16.6	4.37	2.19	2.18	5.0
209.05	4.2	12.0	16.2	4.48	2.19	2.29	5.2
209.40	5.9	13.2	19.1	4.77	2.43	2.34	5.3
209.80	6.5	15.6	22.1	3.38	3.73	0.00	0
210.00	4.4	14.4	18.8	4.05	3.21	0.99	2.3
210.50	3.9	14.4	18.3	3.37	3.51	0.00	0
211.00	9.0	14.4	23.4	3.14	5.45	0.00	0
211.50	11.1	14.4	25.5	2.73	5.99	0.00	0
212.00	11.8	14.4	26.2	3.87	5.16	0.00	0
212.50	9.0	14.4	23.4	3.70	5.02	0.00	0

3. OVERLAY THICKNESS DESIGN SUMMARY

Table 4.9. Summary of Overlay Thickness

Core Location	Everpave© (mm)	AASHTO DARWin (mm)	WSPMS SCOPER (mm)
207.85	50	0	71
208.00	40	0	55
208.50	10	0	56
209.00	95	127	147
209.05	100	132	155
209.40	110	135	143
209.80	35	0	65
210.00	60	58	118
210.50	35	0	90
211.00	10	0	0
211.50	10	0	0
212.00	10	0	0
212.50	10	0	0

As shown in Table 4.9, the three overlay design procedures indicate various required overlay thickness at any given location. The variations between the three overlay design procedures are due in part by the various characteristics and design criteria used by each design method. However, using multiple design procedures allows for a check and balance of the necessary overlay thickness and requires the use of engineering judgment for the final decision.

Due to the difficulty in constructing many changes in overlay thickness, the project should be constructed with logical overlay thickness breaks. For this case study, MP 207.85 to MP 208.50 would require a 45 mm overlay, MP 208.50 to MP 209.40 would require a 100 mm overlay, MP 209.40 to MP 210.50 would require a 45 mm overlay and finally, no structural overlay would be required from MP 211.00 to MP 212.50.

Even though the three overlay design procedures indicate that no overlay is required on the last 2.4 km, it is important to consult the WSPMS to verify that there is no need for rehabilitation on the last section of this project. The WSPMS and core data indicates that rehabilitation would be needed on this section of roadway in 1997 albeit to correct surface cracking. The adjacent project (20 km) to the north was overlaid with 40 mm ACP Class B in 1994. Therefore, for timing purposes, the last 2.4 km should be overlaid with this project. The recommended overlay thickness for that portion of the project would be 45 mm.

The actual rehabilitation of this project consists of two options:

1. Cold in-place recycling from MP 207.80 to MP 210.55, to a maximum thickness of 105 mm and then overlaying with ACP Class F at the following depths:

Milepost	Depth
207.81 to 209.00	45 mm
209.00 to 209.65	60 mm
209.65 to 212.67	45 mm

2. Grind a maximum depth of 90 mm and replace with 90 mm ACP Class F. Then overlay the roadway as indicated by the overlay depths in Option 1.

SECTION 5.0

CASE STUDY NO. 2

SR 7 MP 0.00 to MP 16.82
Morton to Nisqually

This SECTION will describe a WSDOT rehabilitation project which will show each of the overlay design procedures used in the determination of the overlay thickness.

1. INTRODUCTION

This case study comes from a section of State Route (SR) 7 which begins at the community of Morton, Washington (MP 0.00) and proceeds north for 27.1 km to the Nisqually River Bridge (MP 16.82). The 1993 pavement condition survey for this project indicated numerous areas where the pavement is distressed with alligator, transverse and longitudinal cracking. At several locations, Maintenance has placed either an AC patch or a chip seal on the more heavily distressed pavement. According to the WSPMS, this project was projected to reach a program level PSC of 50 in 1994. This overlay project was constructed in 1994.

This area of Lewis County has a terrain that consists of level flood plains to rolling terraces along East Creek and the Tilton River. Elevations range from approximately 244 to 549 meters above sea level. Annual precipitation is 2.4 meters per year. The mean temperature is 11 °C, with a record low and high temperatures of -13 °C and 41°C, respectively. The mean number of days (annually) with temperatures above 32 °C is 6 days and below 0°C is 156 days. Frost penetration near Morton, measured about 230 mm in the record cold winter of 1949-1950.

This section of SR-7 was originally constructed in 1937 with 18 mm of a bituminous surface treatment placed over 204 to 229 mm of select roadway borrow. Construction during 1956 and 1967 placed and additional 24 mm of ACP Class B. A project in 1974 added an additional 61 mm of ACP Class B. A summary of AC core depths, base thickness and core description are listed Table 5.1. The base thickness was taken from the WSPMS.

Table 5.1. Summary of Roadway Surfacing Depths

Core Location	Depth AC (mm)	Depth Base (mm)	Comments
0.23	94	229	Core taken at a crack, crack is full depth
0.43	146	229	Core taken at a crack, crack is full depth
0.98	91	204	Core taken at a crack, top 60 mm is cracked
1.83	198	204	Core taken intact
2.38	168	204	Core taken intact
3.68	155	204	Core taken intact
4.08	128	204	Core taken intact
4.48	168	204	Core taken intact
5.03	128	204	Core taken at a crack, top 46 mm is cracked
5.63	189	204	Core taken at a crack, top 85 mm is cracked
6.13	116	204	Core taken at a crack, crack is full depth
6.48	171	204	Core taken intact
7.18	171	204	Core taken intact
7.73	171	204	Core taken intact
8.23	128	204	Core taken intact
8.78	165	204	Core taken intact
9.48	146	204	Core taken intact
9.98	85	204	Core taken intact
10.58	140	204	Core taken intact
10.98	140	204	Core taken intact
11.63	131	204	Core taken intact
12.18	183	204	Core taken at a crack, top 46 mm is cracked
12.53	171	204	Core taken intact
13.03	204	128	Core taken intact
13.53	152	128	Core taken intact
14.53	213	204	Core taken intact
15.08	152	229	Core taken intact
15.68	168	204	Core taken intact
16.03	287	204	Core taken intact
16.55	207	229	Core taken intact

Current traffic volumes range from 3,600 to 5,000 vehicles per day (two way) with 14 percent trucks. The design period is 15 years and the associated estimated ESALs are 1,200,000.

Table 5.2 summarizes the deflection data that was collected on this project on June 9, 1992. Though the project was over 27 km in length and FWD testing was performed every 75 m, only the FWD data that corresponds to a core location is being evaluated as part of this case study. Knowing the AC layer thickness to within 6 mm is essential in assuring a more accurate prediction of layer moduli in the backcalculation procedure. The average pavement temperature at the time the FWD data was collected was 26 °C. The normalized (40 kN) deflections, Area value (see Volume 2, SECTION 7.0, Paragraph 3.2.2) and the subgrade modulus using the normalized deflections, as determined by Equation 5.1 (see Volume 2, SECTION 7, Paragraph 1.8.3.2), are also shown in Table 5.2.

$$M_R = \frac{(40\ \text{kN})(0.2892)(1000)^2}{(610\ \text{mm})(\text{Defl}_{610})} \qquad (5.1)$$

Table 5.2. FWD Deflections, Area Value and Subgrade Modulus

Core Location	Load (N)	Deflections D0	D203	D305	D610	D915	D1220	Area (mm)	M_R (MPa)
0.23	61 594	552	478	416	279	200	151		
	47 695	520	373	322	211	150	114		
	41 204	454	324	279	180	127	97		
	23 001	253	180	150	92	64	49		
Normalized Values		**418**	**312**	**268**	**174**	**123**	**93**	**511**	**109**
0.43	60 535	431	399	390	347	295	241		
	46 354	327	301	294	261	223	181		
	39 934	280	258	252	225	191	155		
	22 577	148	134	129	114	96	77		
Normalized Values		**279**	**256**	**250**	**222**	**188**	**153**	**759**	**85**
0.98	58 066	1059	791	641	367	229	150		
	45 013	841	625	501	276	167	108		
	38 664	734	541	431	232	139	90		
	21 307	434	304	234	114	65	41		
Normalized Values		**753**	**554**	**443**	**242**	**146**	**95**	**452**	**79**
1.83	64 980	510	384	314	177	105	66		
	49 599	403	308	250	137	79	49		
	43 108	356	271	220	119	68	41		
	25 541	224	169	135	69	38	23		
Normalized Values		**331**	**251**	**203**	**109**	**62**	**38**	**461**	**173**
2.38	62 229	636	423	324	171	117	86		
	47 906	487	330	251	128	86	63		
	41 839	420	286	216	110	73	54		
	23 706	251	165	122	58	40	31		
Normalized Values		**409**	**275**	**208**	**105**	**71**	**53**	**406**	**180**
3.68	61 100	1172	949	817	506	323	208		
	46 707	886	718	615	376	238	154		
	40 075	741	608	518	316	200	129		
	21 801	364	309	266	160	103	68		
Normalized Values		**740**	**606**	**520**	**318**	**202**	**131**	**531**	**60**

Table 5.2. FWD Deflections, Area Value and Subgrade Modulus, continued...

Core Location	Load (N)	Deflections D0	D203	D305	D610	D915	D1220	Area (mm)	M_R (MPa)
4.08	61 523	943	772	660	413	279	203		
	46 918	731	599	510	316	211	152		
	40 427	632	517	439	271	181	131		
	21 872	339	283	239	146	99	72		
Normalized Values		**620**	**509**	**433**	**268**	**180**	**130**	**533**	**71**
4.48	61 100	764	648	572	379	253	173		
	46 707	571	489	431	281	186	127		
	40 075	485	417	365	236	157	106		
	21 448	245	215	184	119	80	55		
Normalized Values		**485**	**416**	**365**	**238**	**158**	**108**	**572**	**80**
5.03	62 017	927	792	697	468	325	236		
	47 060	718	606	531	353	245	179		
	40 569	609	517	451	299	208	152		
	21 801	316	264	227	150	106	79		
Normalized Values		**599**	**507**	**443**	**295**	**205**	**150**	**571**	**64**
5.63	59 195	1207	1013	884	551	342	215		
	45 084	921	777	672	407	250	157		
	39 016	789	664	569	339	207	129		
	20 955	399	333	284	159	97	63		
Normalized Values		**805**	**677**	**585**	**353**	**217**	**136**	**540**	**54**
6.13	62 229	651	568	513	388	293	217		
	47 271	496	426	385	290	218	161		
	40 427	416	362	328	246	184	137		
	21 519	233	181	164	122	91	68		
Normalized Values		**419**	**356**	**323**	**242**	**182**	**135**	**620**	**78**
6.48	58 771	1707	1422	1236	789	478	309		
	44 731	1375	1138	981	611	364	231		
	38 452	1193	986	841	518	306	193		
	20 390	657	542	454	260	153	101		
Normalized Values		**1215**	**1007**	**865**	**536**	**320**	**205**	**535**	**35**
7.18	61 100	1228	1049	929	589	372	237		
	46 707	947	802	706	440	273	174		
	40 075	804	682	598	370	228	145		
	21 237	427	351	304	184	114	74		
Normalized Values		**805**	**680**	**598**	**372**	**232**	**148**	**555**	**51**
7.73	60 183	942	801	660	363	228	170		
	45 860	744	621	511	277	172	130		
	39 722	681	535	438	236	146	110		
	21 166	375	282	236	121	79	60		
Normalized Values		**660**	**536**	**442**	**239**	**149**	**112**	**493**	**80**

Table 5.2. FWD Deflections, Area Value and Subgrade Modulus

Core Location	Load (N)	Deflections D0	D203	D305	D610	D915	D1220	Area (mm)	M_R (MPa)
8.23	61 453	756	616	529	331	231	178		
	47 201	583	470	399	246	173	134		
	40 145	502	398	336	204	144	113		
	20 955	233	202	167	101	73	59		
Normalized Values		**486**	**396**	**336**	**207**	**146**	**114**	**530**	**92**
8.78	60 324	1308	1131	976	586	375	256		
	45 931	1069	922	786	458	288	197		
	39 299	943	809	686	394	244	167		
	21 025	539	459	379	209	129	89		
Normalized Values		**932**	**802**	**681**	**396**	**249**	**170**	**537**	**48**
9.48	58 560	1738	1434	1128	547	281	174		
	46 213	1391	1130	881	401	206	127		
	39 299	1186	969	750	331	172	105		
	21 378	674	534	388	154	80	55		
Normalized Values		**1208**	**983**	**759**	**344**	**177**	**111**	**446**	**55**
9.98	57 925	1705	1357	1111	535	319	222		
	45 155	1403	1089	878	405	235	164		
	38 734	1252	955	759	344	197	136		
	20 813	722	527	401	167	96	66		
Normalized Values		**1251**	**966**	**773**	**356**	**207**	**144**	**446**	**53**
10.58	57 995	1893	1566	1295	622	318	215		
	44 520	1557	1263	1025	470	237	160		
	38 170	1367	1097	883	395	199	134		
	20 178	786	602	466	194	102	71		
Normalized Values		**1393**	**1125**	**912**	**418**	**213**	**144**	**459**	**45**
10.98	59 124	1439	1170	1005	588	320	167		
	45 437	1149	918	782	440	234	123		
	39 440	995	795	667	369	197	102		
	21 731	543	428	349	181	96	53		
Normalized Values		**996**	**798**	**675**	**378**	**203**	**107**	**498**	**50**
11.63	58 489	1517	1267	1075	610	333	186		
	44 802	1205	985	821	450	240	136		
	38 664	1038	844	693	368	197	113		
	20 884	553	445	358	154	103	59		
Normalized Values		**1059**	**868**	**722**	**386**	**214**	**121**	**494**	**49**
12.18	56 373	2389	1967	1693	945	526	319		
	43 108	1820	1515	1291	701	387	233		
	37 535	1677	1322	1122	601	332	201		
	20 602	932	696	580	305	176	114		
Normalized Values		**1727**	**1395**	**1189**	**648**	**361**	**220**	**500**	**29**

Table 5.2. FWD Deflections, Area Value and Subgrade Modulus

Core Location	Load (N)	Deflections D0	D203	D305	D610	D915	D1220	Area (mm)	M_R (MPa)
12.53	58 278	1733	1433	1218	745	478	330		
	44 802	1388	1131	946	564	362	251		
	38 522	1199	976	810	477	305	213		
	20 743	654	515	411	233	151	105		
Normalized Values		**1226**	**999**	**833**	**496**	**319**	**221**	**514**	**38**
13.03	59 406	1270	972	804	540	390	321		
	46 142	996	768	629	418	304	250		
	39 792	895	672	549	361	261	216		
	21 378	509	381	298	191	141	116		
Normalized Values		**883**	**672**	**547**	**362**	**263**	**217**	**504**	**53**
13.53	61 453	953	695	578	337	205	141		
	47 765	752	548	453	260	155	108		
	41 556	653	474	392	223	129	91		
	23 777	396	272	221	122	71	51		
Normalized Values		**634**	**456**	**376**	**214**	**127**	**89**	**459**	**88**
14.53	59 548	975	850	775	584	434	314		
	47 201	771	664	603	448	334	246		
	40 569	661	568	521	383	290	214		
	22 225	366	307	272	209	131	90		
Normalized Values		**654**	**562**	**510**	**381**	**277**	**201**	**622**	**50**
15.08	59 406	1108	926	810	525	350	234		
	46 283	869	724	627	398	262	176		
	39 722	751	622	536	337	220	148		
	21 660	418	334	281	171	112	78		
Normalized Values		**753**	**623**	**538**	**341**	**225**	**152**	**545**	**56**
15.68	59 618	1602	1334	1182	775	489	323		
	45 578	1287	1074	943	597	368	242		
	39 722	1138	946	827	512	313	201		
	21 448	671	537	457	265	159	102		
Normalized Values		**1135**	**939**	**822**	**516**	**319**	**206**	**546**	**37**
16.03	61 029	1021	854	752	495	324	210		
	47 271	814	676	593	381	244	157		
	40 216	708	586	512	326	207	132		
	21 590	394	317	273	167	103	66		
Normalized Values		**694**	**574**	**501**	**321**	**205**	**132**	**550**	**59**
16.55	62 511	760	641	574	406	294	213		
	47 412	599	504	451	314	224	162		
	40 780	518	437	388	269	191	138		
	21 942	308	247	217	147	102	74		
Normalized Values		**510**	**426**	**379**	**264**	**188**	**136**	**584**	**72**

As shown in Table 5.2, the average normalized D0 deflection ranges from 279 µm to 1727 µm and has an average center deflection of 803 µm with a standard deviation of 350 µm. Deflections less than about 760 µm are considered normal.

The Area values shown in Table 5.2 do not suggest an extremely weak AC, such as a loss of stiffness due to stripping. But the Area values indicate that some weakening of the pavement structure does exist. A quick, approximate check of the pavement structure is to compare the actual Area value to see if it falls within the range (normal to low stiffness), above this range (above normal stiffness) or below this range (below low stiffness). This comparison follows (refer to Case Study No. 1 for typical Area Values):

Core Location	AC Thickness (mm)	Actual Area (mm)	Above, Below or Within Range
0.23	94	511	Within
0.43	146	759	Above
0.98	91	452	Below
1.83	198	461	Below
2.38	168	406	Below
3.68	155	531	Below
4.08	128	533	Within
4.48	168	572	Within
5.03	128	571	Within
5.63	189	540	Below
6.13	116	620	Above
6.48	171	535	Below
7.18	171	555	Below
7.73	171	493	Below
8.23	128	530	Below
8.78	165	537	Below
9.48	146	446	Below
9.98	85	446	Below
10.58	140	459	Below
10.98	140	498	Below
11.63	131	494	Below
12.18	183	500	Below
12.53	171	514	Below
13.03	204	504	Below
13.53	152	459	Below

Core Location	AC Thickness (mm)	Actual Area (mm)	Above, Below or Within Range
14.53	213	622	Within
15.08	152	545	Below
15.68	168	546	Below
16.03	287	550	-
16.55	207	584	Below

The above analysis basically suggests minimal structural weakness at MP's such as 0.23, 0.43, 4.08, 4.48, 5.03, 14.53, and 16.03; however, since the actual AC thickness varies, this does not necessarily imply no requirement for a structural overlay.

The elastic modulus values of the subgrade range from 29 MPa to 180 MPa with an average of 69 MPa and a standard deviation of 35 MPa. On average, a subgrade modulus of 100 MPa is typical for Washington state. This large variation in stiffness is most likely due to variation in soil moisture and the proximity of underlying rock, more than actual soil or deposition changes along the roadway.

Though there is substantial variation in the pavement deflections, Area values, and subgrade modulus, there doesn't appear to be a consistent pattern to isolate separate sections for this project. Figure 5.1 graphically shows how the normalized center deflection, normalized Area value and subgrade modulus varies throughout the projects length. Figure 5.1 was created from an in-house computer program and this program has yet to be converted to metric units. Therefore, Figure 5.1 shows the center deflection in mils, the Area value in inches and the subgrade modulus in ksi.

2. OVERLAY DESIGN PROCEDURES

This SECTION describes three overlay design procedures that are currently used by WSDOT: 1) WSPMS SCOPER, 2) WSDOT Empirical-Mechanistic Overlay Design, and 3) AASHTO Overlay Design Procedure. The three procedures can be used as design checks as will be more fully described later.

2.1 WSPMS SCOPER OVERLAY DESIGN PROCEDURE

WSPMS SCOPER is partially based on the Asphalt Institutes Component Analysis procedure (see Volume 2, SECTION 7.0, Paragraph 1.3). Specific modifications made by WSDOT can be found in "Washington State Pavement Management - A 1993 Update," Research Report WA-RD 274.1, Washington State Department of Transportation, Olympia, Washington, 1993.

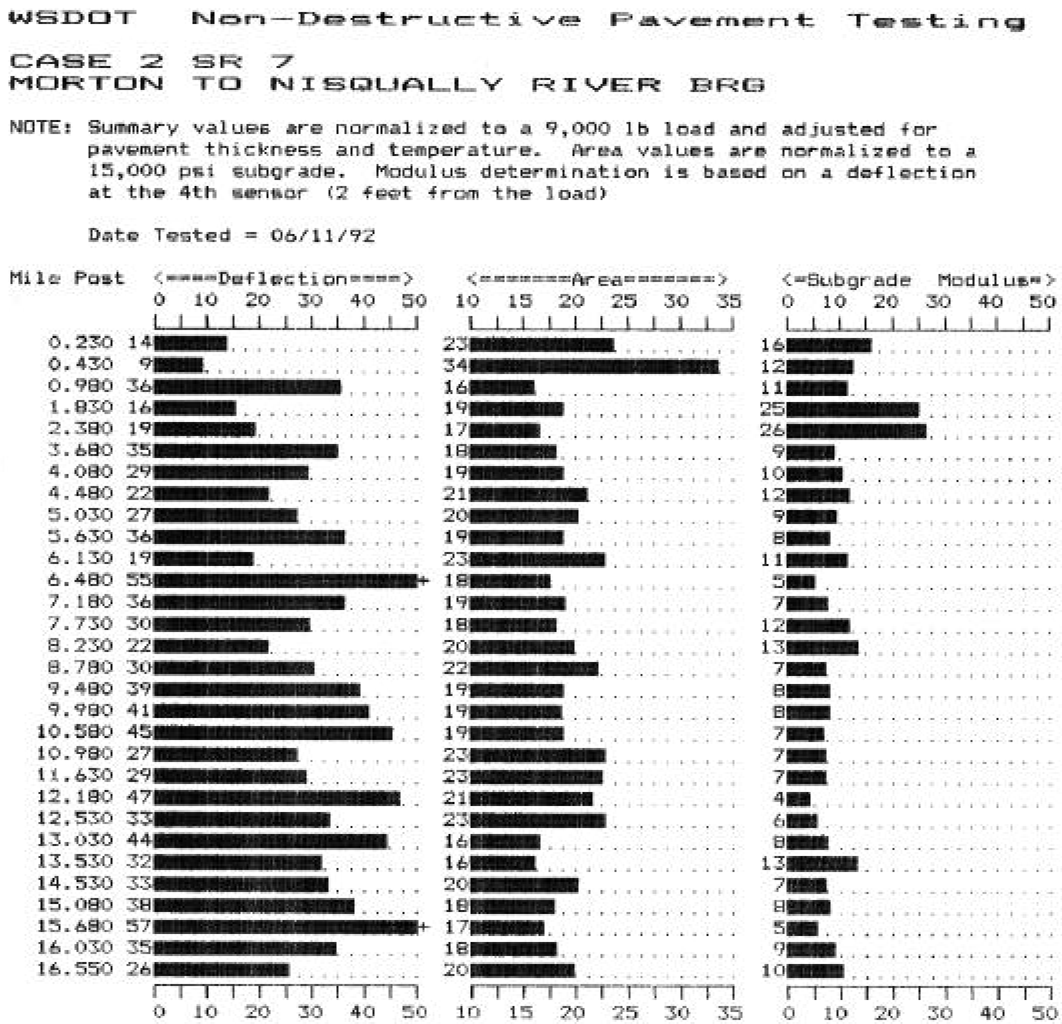

Figure 5.1. Normalized Center Deflection, Area Value, and Subgrade Modulus

The WSPMS SCOPER uses a component analysis approach that essentially requires the total pavement structure to be developed as a new design for the specified service conditions and then compared to the existing pavement structure (taking into account both pavement condition, type, and thickness of the pavement layers). The component design process requires substantial engineering judgment. This judgment is mainly associated with the selection of "weighting factors" or "conversion factors" to use in evaluating the structural adequacy of the existing pavement layers. The SCOPER design approach uses relationships between subgrade strength, pavement structure, and traffic to determine the overlay thickness.

2.1.1. EXAMPLE OF CALCULATIONS

Layer coefficients and ESAL's were determined using the WSPMS. The subgrade modulus as determined from the FWD analysis as shown in Table 5.2 was used in this analysis. Refer to Table 5.3 for SCOPER overlay design results. To illustrate this process, MP 0.23 will be used as an example:

MP 0.23

(94 mm AC)(0.82)	=	77 mm
(229 mm Base)(0.30)	=	69 mm
Effective Thickness	=	146 mm

M_R = 109 MPa
ESAL = 1 200 000

Refer to Design Thickness charts in Asphalt Institutes MS-1 Manual or Volume 2, SECTION 7.0, Paragraph 1.3.

Design Thickness	=	195 mm
Effective Thickness	=	146 mm
Overlay Thickness	=	49 mm

Table 5.3. WSPMS SCOPER Overlay Design Procedure

Core Locations	Depths AC (mm)	Depths Base (mm)	Layer Coefficients AC	Layer Coefficients Base	Subgrade Modulus (MPa)	Thickness (mm) Design	Thickness (mm) Effective	Thickness (mm) Overlay
0.23	94	229	0.82	0.30	109	195	146	49
0.43	146	229	0.82	0.30	85	213	189	24
0.98	91	204	0.82	0.30	79	219	137	82
1.83	198	204	0.64	0.30	173	162	189	0
2.38	168	204	0.64	0.30	180	158	168	0
3.68	155	204	0.78	0.30	60	235	183	52
4.08	128	204	0.75	0.30	71	226	155	71
4.48	168	204	0.75	0.30	80	216	186	30
5.03	128	204	0.66	0.30	64	232	146	86
5.63	189	204	0.66	0.30	54	241	186	55
6.13	116	204	0.62	0.30	78	219	131	88
6.48	171	204	0.62	0.30	35	262	165	98
7.18	171	204	0.62	0.30	51	244	165	79

Table 5.3. WSPMS SCOPER Overlay Design Procedure, continued...

Core Locations	Depths AC (mm)	Depths Base (mm)	Layer Coefficients AC	Layer Coefficients Base	Subgrade Modulus (MPa)	Thickness (mm) Design	Thickness (mm) Effective	Thickness (mm) Overlay
7.73	171	204	0.62	0.30	80	216	165	52
8.23	128	204	0.51	0.30	92	207	125	82
8.78	165	204	0.51	0.30	48	247	146	101
9.48	146	204	0.51	0.30	55	241	134	107
9.98	85	204	0.51	0.30	53	241	107	134
10.58	140	204	0.55	0.30	45	250	137	113
10.98	140	204	0.55	0.30	50	244	137	107
11.63	131	204	0.62	0.30	49	247	140	107
12.18	183	204	0.62	0.30	29	271	174	98
12.53	171	204	0.62	0.30	38	259	165	94
13.03	204	128	0.51	0.30	53	241	143	98
13.53	152	128	0.51	0.30	88	210	116	94
14.53	213	204	0.51	0.30	50	244	171	73
15.08	152	229	0.61	0.30	56	238	162	76
15.88	168	204	0.69	0.30	37	259	177	82
16.03	287	204	0.69	0.30	59	235	256	0
16.55	207	229	0.82	0.30	72	223	241	0

2.2 WSDOT MECHANISTIC-EMPIRICAL OVERLAY DESIGN

2.2.1. EVERCALC©

Currently, when a pavement structure is analyzed using FWD data and a backcalculation procedure, it is recommended to vary the use and stiffness of the stiff layer. A stiff layer should be used when the underlying material is known to be saturated or if underlying rock or other very stiff deposits are known to exist (refer to Volume 2, SECTION 7.0, Paragraph 3.3.4). In most instances, the presence, the stiffness, and depth to stiff layer is not known. Therefore, by evaluating the data using no stiff layer, a stiff layer at 345 MPa (50,000 psi), which indicates a saturated layer, and a stiff layer at 6 895 MPa (1,000,000 psi), which indicates a rock layer or stiff deposit, would help in identifying the modulus characteristic of the pavement layers.

2.2.1.1 Input Values

General Data

Number of layer = 3 (no stiff layer)
4 (stiff layer)

Units = Metric
Indicate whether or not a stiff layer option is to be used
Temperature correction to be applied
Temperature Measurement = Direct Method
Plate radius = 15 cm
Seed Moduli = User supplied

Sensor No.	1	2	3	4	5	6
Radial Offset (cm)	0	205	305	610	915	1220

Layer Information is shown in Table 5.4.

Table 5.4. Layer Characteristics Input Values

Layer	Description	Poisson's Ratio	Modulus (MPa) Initial	Minimum	Maximum
1	AC	0.35	2 758	689	13 790
2	Base	0.40	172	34	3 447
3	Subgrade	0.45	103	34	3 447
4*	Stiff layer (water)	0.35	345		
4*	Stiff layer (rock)	0.30	6 895		

* Denotes the use of a stiff layer.

Deflection Data

Refer to Volume 3, SECTION 2.0 for the necessary procedures for entering deflection data or for converting the raw FWD deflection file into Evercalc ©.

Backcalculation Results

The backcalculation layer moduli, for all three cases (no stiff layer and stiff layers at 345 and 6 895 MPa) are shown in Table 5.5.

Table 5.5. Summary of EVERCALC Results

Core Location	No Stiff Layer Eadj[1] (kPa)	Eac[2] (MPa)	Ebase (MPa)	Esub (MPa)	RMS	Depth to Stiff Layer (m)	Stiff Layer @ 345 MPa Eadj (MPa)	Eac (MPa)	Ebase (MPa)	Esub (MPa)	RMS	Stiff Layer @ 6 895 MPa Eadj (MPa)	Eac (MPa)	Ebase (MPa)	Esub (MPa)	RMS
0.23	2861	1186	655	90	0.78	15.24	2613	**1082**[3]	**772**	**97**	2.05	1737	724	1000	97	2.46
0.43	33212	13790	1834	48	2.19	15.24	33212	13790	2075	48	1.92	33212	13790	2110	48	1.89
0.98	16023	6653	41	83	4.57	5.08	5481	**2275**	**179**	**69**	0.83	4875	2027	214	62	0.77
1.83	1503	2441	41	221	1.94	2.07	**1048**	1696	**179**	**124**	1.71	752	1220	531	76	6.65
2.38	710	1151	172	159	1.52	5.08	**538**	869	**290**	**152**	4.43	503	814	400	124	7.60
3.68	1331	2158	34	62	2.35	2.81	**745**	1213	**228**	**34**	2.41	758	1227	234	34	5.27
4.08	2048	3330	110	62	0.69	4.95	**1076**	1751	**324**	**55**	2.84	1000	1620	372	48	3.49
4.48	2392	3882	34	83	0.88	3.86	**1641**	2661	**221**	**55**	1.46	1462	2372	296	48	2.05
5.03	3096	4240	145	55	0.52	5.96	**1848**	2537	**372**	**48**	1.81	1710	2351	407	48	2.18
5.63	758	1034	34	55	5.03	2.54	**1213**	1669	**41**	**34**	5.25	1262	1724	34	34	10.44
6.13	7295	9997	476	62	1.21	7.97	**3689**	5061	**958**	**55**	0.67	3530	4847	1014	55	0.76
6.48	538	738	34	34	6.41	2.71	**607**	827	**34**	**34**	25.63	593	814	34	34	30.30
7.18	1096	1503	34	55	4.13	2.72	**1806**	2482[4]	**34**	**34**	4.94	1737	2386	34	34	10.12
7.73	889	1220	55	76	2.24	4.31	**641**	876	**159**	**62**	5.92	600	820	196	55	6.88
8.23	1538	2110	310	76	2.05	15.24	**1234**	1689	**414**	**83**	3.56	1200	1648	434	76	3.83
8.78	862	1186	34	48	2.88	3.80	**855**	1172	**83**	**34**	4.16	1358	1862	34	34	6.49
9.48	1758	689	34	62	13.77	1.42	4295	**1682**	**34**	**34**	34.28	5564	2186	34	34	46.16
9.98	6833	2682	34	48	4.63	4.58	5337	**2096**	**69**	**41**	3.64	4895	1917	83	41	4.63
10.58	1758	689	34	48	13.48	1.33	3241	**1269**	**34**	**34**	47.07	4185	1641	34	34	57.33
10.98	2916	1145	34	62	13.98	1.61	6584	**2586**[5]	**34**	**34**	23.99	7412	2910	34	34	35.60

[1] Eac is the actual backcalculated modulus for the AC at the insitu field temperatures.
[2] Eadj is Eac adjusted to a standard temperature of 25C (77F).
[3] Bold numbers indicate the moduli that were selected for input into EVERPAVE. Moduli are selected based on engineering judgment and low RMS.
[4] Base moduli "fixed" at 138 MPa in EVERCALC. This resulted in an AC modulus of 1138 MPa and a subgrade modulus of 34 MPa. These re-calculated moduli values were entered into EVERPAVE
[5] Base moduli "fixed" at 138 MPa in EVERCALC. This resulted in an AC modulus of 696 MPa and a subgrade modulus of 34 MPa. These re-calculated moduli values were entered into EVERPAVE.

Table 5.5. Summary of EVERCALC Results, continued...

Core Location	No Stiff Layer Eadj (kPa)	Eac (MPa)	Ebase (MPa)	Esub (MPa)	RMS	Depth to Stiff Layer (m)	Stiff Layer @ 345 MPa Eadj (MPa)	Eac (MPa)	Ebase (MPa)	Esub (MPa)	RMS	Stiff Layer @ 6 895 MPa Eadj (MPa)	Eac (MPa)	Ebase (MPa)	Esub (MPa)	RMS
11.63	6074	1234	34	55	11.25	1.68	13507	**2744**5	**34**	**34**	26.25	14975	3041	34	34	36.36
12.18	3399	689	34	34	22.43	1.89	3399	**689**	**34**	**34**	49.19	3399	689	34	34	54.38
12.53	3820	772	34	34	1.81	4.10	4475	**910**	**34**	**34**	13.84	4406	896	34	34	16.87
13.03	3399	689	165	41	4.34	15.24	3399	**689**	**276**	**41**	6.35	3399	689	283	41	6.51
13.53	945	1937	34	97	3.06	2.54	338	**689**[6]	**758**	**55**	6.89	338	689	1151	48	9.53
14.53	1048	2151	55	41	1.88	9.31	820	**1689**	**172**	**41**	1.25	793	1627	207	34	1.33
15.08	1276	2627	34	55	1.41	2.81	1014	**2075**	**138**	**34**	5.11	2089	4295	34	34	8.91
15.68	462	951	34	34	4.92	2.95	531	**1089**	**34**	**34**	21.56	517	10666	34	34	25.96
16.03	338	689	34	62	7.49	2.83	393	**807**	**34**	**34**	2.39	414	848	34	34	3.66
16.55	1117	2296	69	62	0.75	6.75	889	**1834**	**193**	**55**	0.68	841	1724	214	55	0.86

[6] Base moduli "fixed at 138 MPa in EVERCALC. This resulted in an AC modulus of 2606 MPa and a subgrade modulus of 34 MPa. These re-calculated moduli values were entered into EVERPAVE.

At several MP locations the Eadj moduli values appear to be unrealistically high, therefore the unadjusted Eac moduli were selected for input for EVERPAVE

2.2.2. EVERPAVE©

Everpave© is a mechanistic-empirical overlay design procedure that was developed by WSDOT. The pavement analysis is accomplished by use of Everstress © (used as a subroutine, see Volume 3, SECTION 1.0), which can account for the stress sensitive characteristics of the unbound materials. Everpave © uses the material properties (modulus) of each pavement layer (e.g. AC, base and subgrade). traffic load repetitions and the environment (weather) to determine the appropriate overlay design thickness. The determination of the appropriate thickness is based on the two primary distresses found in flexible pavements in Washington State; rutting and fatigue cracking (see Volume 2, SECTION 7.0, Paragraph 1.6). The Everpave © program calculates the overlay thickness by comparing the pavement performance lives for fatigue and rutting with the projected design traffic volume (ESALs). When the minimum repetitions of the two failure criteria is greater than the traffic volume, the final overlay thickness is produced. Otherwise, the overlay thickness is increased by an incremental thickness and the analysis is repeated.

2.2.2.1 Input Values

General Input Data (see Volume 2, SECTION 7.0, Paragraph 1.6)

Tire Load	20 000 N
Tire Pressure	689 kPa
Shift factor for New AC	10
Shift factor for Existing AC	10
Dual Tire Spacing	35.6 cm

	Spring	Summer	Fall	Winter
Seasonal Variation				
Base Course	0.85	1.00	0.90	0.75
Subgrade	0.85	1.00	0.90	0.85
Traffic	1.00	1.00	1.00	1.00
Mean Air Temperature °C	9.2	16.7	10.4	3.6
Season Period (months)	3	4	2	3

For mean air temperature refer to Volume 2, SECTION 7.0, Appendix 7.1, Table 1 and for seasonal periods (months) refer to Table 7.4, Volume 2, SECTION 7.0, Paragraph 1.6.

Pavement Data

Overlay AC Moduli	=	2 758 MPa
Poisson's ratio	=	0.35
Initial Overlay Thickness	=	0.5 cm
Thickness Increment	=	0.5 cm

Traffic Data

80 kN ESAL's for Design Period (15 years)	=	1 200 000
Lane Distribution Factor	=	1.00
Total Design ESAL's	=	1 200 000

The results of the Everpave© overlay analysis are presented in Table 5.6. As a reminder, the initial overlay thickness was established at 5 mm for this case study. Therefore, those locations that indicate a 5 mm overlay, are more likely based on the initial overlay thickness set by the user.

Table 5.6. Everpave© Overlay Thickness Results

Core Location	AC (cm)	Base (cm)	Selected Layer Moduli Eac (MPa)	Ebase (MPa)	Esub (MPa)	Everpave© Overlay (mm)
0.23	9.4	22.9	1 082	772	97	5
0.43	14.6	22.9	-	-	-	-
0.98	9.1	20.4	2 275	179	124	45
1.83	19.8	20.4	1 048	179	124	5
2.38	16.8	20.4	538	290	152	5
3.68	15.5	20.4	745	228	34	40
4.08	12.8	20.4	1 076	324	55	20
4.48	16.8	20.4	1 641	221	55	5
5.03	12.8	20.4	1 848	372	48	10
5.63	18.9	20.4	1 213	41	34	15
6.13	11.6	20.4	3 689	958	55	5
6.48	17.1	20.4	607	34	34	70
7.18	17.1	20.4	1 138	138	34	20

Table 5.6. Everpave© Overlay Thickness Results, continued...

Core Location	AC (cm)	Base (cm)	Selected Layer Moduli Eac (MPa)	Ebase (MPa)	Esub (MPa)	Everpave© Overlay (mm)
7.73	17.1	20.4	641	139	62	25
8.23	12.8	20.4	1 234	414	83	5
8.78	16.5	20.4	855	83	34	45
9.48	14.6	20.4	1 682	34	34	40
9.98	8.5	20.4	2 096	69	41	80
10.58	14.0	20.4	1 269	34	34	60
10.98	14.0	20.4	696	138	34	70
11.63	13.1	20.4	696	138	34	75
12.18	18.3	20.4	689	34	34	55
12.53	17.1	20.4	910	34	34	50
13.03	20.4	12.8	689	276	41	15
13.53	15.2	12.8	2 606	138	34	10
14.53	21.3	20.4	820	172	41	5
15.08	15.2	22.9	1 014	138	34	35
15.68	16.8	20.4	531	34	34	80
16.03	28.7	20.4	393	34	34	10
16.55	20.7	22.9	889	193	55	5

2.3 AASHTO - DARWin PAVEMENT DESIGN SYSTEM

DARWin is the computerized version of the pavement design models presented in AASHTO's "Guide for Design of Pavement Structures 1993." As stated in the DARWin User's Guide, "In the AASHTO overlay design procedure, the structural capacity for future traffic (SC_f) and the effective structural capacity (SC_{eff}) of the existing pavement are calculated using one of up to four available methods. These structural capacities are then used to determine the required overlay structural capacity". For this case study, the non-destructive testing method will be used for overlay determination. DARWin uses the deflection data to backcalculate the subgrade modulus (M_R) and the effective pavement modulus (E_p). These values are then used to determine the structural numbers for the existing pavement and for future traffic volumes. The required overlay structural number is the difference between SC_f and SC_{eff}.

2.3.1. INPUT VALUES

18 k ESAL's	1 200 000
Initial Serviceability	4.5
Terminal Serviceability	3.0
Reliability Level (%)	50

Overall Standard Deviation	0.50
Overlay Layer Coefficient (a_{ol})	0.44

Calculated Overlay Structural Number (SN_{ol}) = Non-Destructive Method

<u>Point-by-Point Backcalculation</u>

FWD Load	9000 lbs
Resilient Modulus Correction Factor	0.5
Base Type	Granular

Mid-depth Pavement Temperature	92°F MP 0.00 to MP 1.23
	67°F MP 1.28 to MP 4.23
	71°F MP 4.53 to MP 8.93
	93°F MP 8.98 to MP 11.33
	103°F MP 11.38 to MP 13.33
	62°F MP 13.38 TO MP 16.81

The normalized load (9000 lbs) and corresponding deflections are shown in Table 5.7. WSDOT uses a FWD sensor spacing of 0, 8, 12, 24, 36, and 48 inches. DARWin will accommodate deflection data collected at any deflection spacing and at any load level. The FWD sensor spacing was selected such that the deflection basin would be adequately defined. Typically, the pavement structural design is based on a legally loaded axle of 18,000 lbs (9000 lbs per one-half of the axle). Therefore, the normalized deflections at 9000 lbs are used in this procedure. Results of this analysis are shown in Table 5.8.

Table 5.7. Normalized Deflection Data

MP	Load (lbs)	$D_{at\ 0”}$ (mils)	$D_{at\ 8”}$ (mils)	$D_{at\ 12”}$ (mils)	$D_{at\ 24”}$ (mils)	$D_{at\ 36”}$ (mils)	$D_{at\ 48”}$ (mils)
0.23	9000	16.44	12.30	10.56	6.84	4.85	3.68
0.43	9000	10.97	10.09	9.84	8.75	7.42	6.03
0.98	9000	29.65	21.83	17.43	9.51	5.76	3.74
1.83	9000	13.02	9.89	8.00	4.31	2.46	1.51
2.38	9000	16.11	10.82	8.17	4.14	2.80	2.08
3.68	9000	29.14	23.87	20.47	12.52	7.97	5.16
4.08	9000	24.39	20.05	17.05	10.56	7.09	5.13
4.48	9000	19.09	16.39	14.36	9.38	6.24	4.25
5.03	9000	23.57	19.96	17.43	11.60	8.07	5.90
5.63	9000	31.71	26.65	23.02	13.88	8.54	5.37
6.13	9000	16.50	14.03	12.70	9.53	7.17	5.33
6.48	9000	47.85	39.65	34.05	21.09	12.59	8.07
7.18	9000	31.69	26.79	23.53	14.65	9.14	5.83
7.73	9000	25.97	21.11	17.41	9.39	5.88	4.42
8.23	9000	19.15	15.60	13.21	8.13	5.74	4.47
8.78	9000	36.70	31.56	26.83	15.58	9.79	6.71
9.48	9000	47.54	38.69	29.89	13.54	6.97	4.37
9.98	9000	49.27	38.03	30.45	14.01	8.16	5.66
10.58	9000	54.85	44.31	35.89	16.44	8.37	5.66
10.98	9000	39.21	31.43	26.56	14.90	7.98	4.20
11.63	9000	41.69	34.19	28.44	15.21	8.41	4.76
12.18	9000	67.99	54.92	46.81	25.50	14.20	8.66
12.53	9000	48.27	39.32	32.79	19.54	12.54	8.71
13.03	9000	34.77	26.45	21.55	14.24	10.34	8.53
13.53	9000	24.97	17.94	14.81	8.44	5.01	3.50
14.53	9000	25.75	22.13	20.09	15.01	10.92	7.93
15.08	9000	29.66	24.53	21.19	13.42	8.85	5.97
15.68	9000	44.69	36.96	32.35	20.31	12.54	8.18
16.03	9000	27.31	22.59	19.74	12.64	8.07	5.19
16.55	9000	20.09	16.77	14.93	10.38	7.39	5.35

Table 5.8. AASHTO DARWin Overlay Thickness Results

Core Location	Pavement Depths AC (in)	Base (in)	Total (in)	SN for Future Traffic	Effective Existing Pavement SN	Calculated Overlay SN (SN_{ol})	Overlay Thickness (in)
0.23	3.72	9.00	12.72	3.08	3.02	0.06	0.1
0.43	5.76	9.00	14.76	-	-	-	-
0.98	3.60	8.04	11.64	3.52	2.13	1.39	3.2
1.83	7.80	8.04	16.08	2.56	3.20	0.00	0.0
2.38	6.60	8.04	14.64	2.52	2.61	0.00	0.0
3.68	6.12	8.04	14.16	3.92	2.39	1.53	3.5
4.08	5.04	8.04	13.08	3.67	2.41	1.26	2.9
4.48	6.60	8.04	14.64	3.50	2.93	0.57	1.3
5.03	5.04	8.04	13.08	3.80	2.63	1.17	2.7
5.63	7.44	8.04	15.48	4.08	2.54	1.54	3.5
6.13	4.56	8.04	12.60	3.52	3.10	0.42	1.0
6.48	6.72	8.04	14.76	4.75	2.15	2.60	5.9
7.18	6.72	8.04	14.76	4.16	2.50	1.66	3.8
7.73	6.72	8.04	14.76	3.50	2.49	1.01	2.3
8.23	5.04	8.04	13.08	3.30	2.66	0.64	1.5
8.78	6.48	8.04	14.52	4.26	2.30	1.96	4.5
9.48	5.76	8.04	13.80	4.04	1.81	2.23	5.1
9.98	3.36	8.04	11.40	4.09	1.55	2.54	5.8
10.58	5.52	8.04	13.56	4.34	1.95	2.39	5.4
10.98	5.52	8.04	13.56	4.19	2.36	1.83	4.2
11.63	5.16	8.04	13.20	4.22	2.39	1.83	4.2
12.18	7.20	8.04	15.24	4.77	2.21	2.56	5.8
12.53	6.72	8.04	14.76	4.56	2.58	1.98	4.5
13.03	8.04	5.04	13.08	4.25	2.97	1.28	2.9
13.53	6.00	5.04	11.04	3.35	1.92	1.43	3.3
14.53	8.40	8.04	16.44	4.34	3.02	1.32	3.0
15.08	6.00	9.00	15.00	4.03	2.44	1.59	3.6
15.68	6.60	8.04	14.64	4.69	2.10	2.59	5.9
16.03	11.28	8.04	19.32	3.87	3.00	0.87	2.0
16.55	8.16	9.00	17.16	3.74	3.2	0.52	1.2

2.4 OVERLAY THICKNESS DESIGN SUMMARY

Table 5.9. Summary of Overlay Thickness

Core Location	Everpave© (mm)	AASHTO DARWin (mm)	WSPMS SCOPER (mm)
0.23	5	0	49
0.43	-	-	24
0.98	45	81	82
1.83	5	0	0
2.38	5	0	0
3.68	40	89	52
4.08	20	74	71
4.48	5	33	30
5.03	10	69	86
5.63	15	89	55
6.13	5	25	88
6.48	70	150	98
7.18	20	97	79
7.73	25	58	52
8.23	5	38	82
8.78	45	114	101
9.48	40	130	107
9.98	80	147	134
10.58	60	137	113
10.98	70	107	107
11.63	75	107	107
12.18	55	147	98
12.53	50	114	94
13.03	15	74	98
13.53	10	84	94
14.53	5	76	73
15.08	35	91	76
15.68	80	150	82
16.03	10	51	0
16.55	5	30	0

As discussed in the previous case study, the project should be constructed with logical breaks in the overlay thickness. The variations between the three overlay design procedures are due in part by the various characteristics and design criteria used by each design method. However, using multiple design procedures allows for a check and balance of the necessary overlay thickness and requires the use of engineering judgment for the final decision.

The actual limits of the overlay may vary due to actual field conditions and limitations. As a note, this roadway was last overlaid in 1974 with 60 mm AC, the project from MP 6.42 to MP 16.55 received an additional chip seal in 1987. It can be assumed that the majority of the severely distressed pavement will be removed and reconstructed. With this assumption, the required overlay thickness for this project would be as follows:

MP Limits	Overlay Thickness (mm)
0.00 to 9.48	45 mm
9.48 to 12.53	60 mm
12.53 to 16.55	45 mm

The actual rehabilitation of this project included sealing of all cracks, preleveling as necessary with ACP Class G to correct rutted and settled pavement, dig outs as necessary to correct the severely distressed pavement and overlaying the entire project with the following AC thickness:

MP Limits	Overlay Thickness (mm)
0.00 to 1.00	60 mm
1.00 to 6.00	45 mm
6.00 to 13.00	60 mm
13.00 to 16.82	45 mm

SECTION 6.0

CASE STUDY NO. 3

I 90 MP 275.50 to MP 280.16
Spokane West UAB to Spokane Viaduct

This SECTION will describe a WSDOT rehabilitation project which will illustrate the design of a new roadway section, for both a flexible and rigid pavement.

1. INTRODUCTION

This case study comes from a section of Interstate 90 which begins at the west UAB for Spokane, Washington (MP 275.50) and proceeds east to the Spokane Viaduct (MP 280.16). This project addresses the need to rehabilitate the distressed concrete pavement, replace the existing drainage system and reconstruct the roadway shoulders and slopes. This project was reconstructed in 1994 and 1995.

The predominant soil type in this area is loam, of the Marble, Hesseltine, and Cheney Groups. There are some rock outcroppings and Hesseltine Very Rock Complex areas from MP 277.20 to MP 279.20. From MP 275.50 to MP 277.50 the roadway traverses a generally flat plateau. Between MP 277.50 to MP 279.50, the roadway drops at a five percent grade to a structure over Latah Creek. From the structure to the end of the project, the roadway rises at a more gradual slope.

This section of I-90 was originally constructed from 1964 to 1966 with 200 mm of plain jointed (4.6 m joint spacing) portland cement concrete, over 60 mm of crushed surfacing top course, over 75 mm of special gravel base, over a sandy subgrade with some silt.

Current traffic volumes are around 30,000 (two way) vehicles per day with 12 percent trucks. The design period is 40 years and the associated estimated ESALs are 65,000,000.

Prior to rehabilitation, this roadway section was distressed with severe transverse cracking, joint spalling and faulting. In addition, the original drainage system was undersized for an area with poor soil drainage characteristics and the potential for underground springs.

2. NEW/RECONSTRUCTION DESIGN PROCEDURES

The design process to be used for new or reconstructed pavements will be according to the AASHTO Guide for Design of Pavement Structures (1986 or later version), see Volume 1, SECTION 2.0, Paragraph 3.).

2.1 FLEXIBLE STRUCTURAL DESIGN

Refer to Volume 2, SECTION 5.0 for discussion on the AASHTO flexible design procedure. WSDOT input values can be found in Volume 2, SECTION 5.0, Paragraph 2.3.2. The DARWin pavement design system will be used in the determination of pavement depths for this case study.

2.1.1 INPUT VALUES

18-kip ESALs Over Initial Performance Period	=	65,000,000
Initial Serviceability	=	4.5
Terminal Serviceability	=	3.0
Reliability (percent)	=	95
Overall Standard Deviation	=	0.50
Roadbed Soil Resilient Modulus (psi) [1]	=	17,000

[1]Note: Assumes subgrade modulus @ 15,000 psi for 5 months per year and @ 20,000 psi for 7 months of the year.

Stage Construction	=	1
Design Structural Number	=	5.55

2.1.2 SPECIFIED THICKNESS DESIGN

A number of material types (ACP Class A, E, ATPB, CSTC, CSBC, etc..) can be used in the determination of the pavement section. The materials and thickness shown below were chosen as an example. Typical roadway sections could be as follows:

Without Drainable Layer (Without Improved Subsurface Drainage)	With Drainable Layer (Improved Subsurface Drainage)
105 mm ACP Class A	105 mm ACP Class A
175 mm ACP Class E	145 mm ACP Class E
135 mm CS	100 mm ATPB
415 mm Total	135 mm CS
	485 mm Total

The layer coefficients used were:

$a_{ACP\ A,\ E}$ = 0.44
$a_{ACP\ ATPB,\ CS}$ = 0.13

The ACP Class A was fixed at 105 mm and the CS at 135 mm (minimums noted in Volume 1, SECTION 2.0, Tables 2.1 and 2.2). The ATPB drainage was set at 100 mm. The remaining pavement thickness to achieve the design SN was allocated to the ACP Class E.

The above might suggest that the two sections will have equal performance, this is unlikely.

2.1.3 FROST CONSIDERATIONS

By use of Figure 2.36 (Volume 2, SECTION 2.0), the expected depth of freeze in the vicinity of Spokane is about 45 in. (1100 mm) based on the severe winter of 1949-1950. By classifying the subgrade as fine-grained, the maximum depth of freeze is about 35 in. (890 mm) based on Figure 2.34 (Volume 2, SECTION 2.0). By selecting an approximate depth of freeze of 1 000 mm, then one-half of this depth is 500 mm. The two pavement sections shown in Paragraph 2.1.2 above have total depths of 415 and 485 mm, respectively. If the subgrade soil is classified as frost susceptible, then increase the pavement section to one-half the expected frost depth (i.e. 500 mm) by adding additional thickness of CS.

2.2 RIGID STRUCTURAL DESIGN

Refer to Volume 2, SECTION 6.0 for discussion on the AASHTO rigid design procedure. WSDOT input values can be found in Volume 2, SECTION 6.0, Paragraph 2.2. The DARWin pavement design system will be used in the determination of pavement depths for this case study.

2.2.1 INPUT VALUES

18-kip ESALs Over Initial Performance Period	=	65,000,000
Initial Serviceability	=	4.5
Terminal Serviceability	=	3.0
28-day mean PCC Modulus of Rupture (psi)	=	650
28-day mean Elastic Modulus of Slab (psi)	=	4,000,000
Mean Effective k-value (psi/in) [1]	=	490 (assumes use of ATPB)
Reliability (percent)	=	95
Overall Standard Deviation	=	0.40

Load Transfer Coefficient, J	=	2.7 (assumes use of dowel bars)
Overall Drainage Coefficient, Cd	=	1.20

[1]Note: Assumes ATPB @ 100,000 psi and subgrade @ 15,000 psi for 5 months per year and @ 20,000 psi for 7 months per year. Loss of support = 0.5.

Stage Construction	=	1
Calculated Design Thickness (in)	=	11.98

Therefore, a rigid pavement section would include:

305 mm (12 inches) of doweled concrete pavement
100 mm (0.33 ft) ATPB
105 mm (0.35 ft) CSBC or geotextile[2]
510 mm Total

[2]Note: The geotextile or CSBC material is needed to act as a filter layer for the ATPB (refer to Volume 1, SECTION 2.0, Figure 2.2).

Reconstruction of this section of I-90 involved removing the existing concrete pavement and base material, installation of the drainage system, and rebuilding with 280 mm (11 inches) of doweled concrete pavement (4.57 m (15 ft) joint spacing) over 100 mm (0.33 ft) ATB, over 60 mm (0.20 ft) crushed surfacing.

2.2.2 FROST CONSIDERATIONS

From Paragraph 2.1.3 above, one-half of the design frost depth is about 500 mm. The recommended pavement section has a total depth of 510 mm. If the subgrade soil is frost susceptible, then no additional thickness is needed to meet the minimum frost requirement.

SECTION 2.0, APPENDIX 2.1

BACKCALCULATION GUIDELINES

1. INTRODUCTION

The general guidelines which follow are rather broad in scope and should be considered only "rules-of-thumb" at best. These guidelines were developed from WSDOT experience and the SHRP LTPP Expert Task Group for Deflection Testing and Backcalculation. Undoubtedly, they will change and software such as Evercalc © will continue to be improved.

2. GUIDELINES

2.1 NUMBER OF LAYERS

Generally, one should use no more than 3 or 4 layers of unknown moduli in the backcalculation process (preferably, no more than 3 layers).

If a three layer system is being evaluated, and questionable results are being produced (extremely weak base moduli, for example), it is sometimes advantageous to evaluate this pavement structure as a two layer system. This modification would possibly indicate that the base material has been contaminated by the underlying subgrade and is weaker due to the presence of fine material. Alternatively, a stiff layer should be considered if not done so previously.

If a pavement structure consists of a stiffer layer between two weak layers, it may be difficult to obtain realistic backcalculated moduli. For example, a pavement structure which consists of asphalt concrete over a cement treated base.

2.2 THICKNESS OF LAYERS

2.2.1 SURFACING

It can be rather difficult to "accurately" backcalculate AC/BST moduli for bituminous surface layers less than 75 mm (3 inches) thick. Such backcalculation can be attempted for layers less than 75 mm (3 inches), but caution is suggested. In theory, it is possible to backcalulate separate layer moduli for various types of bituminous layers within a flexible pavement. Generally, it is not advisable to do this since one can quickly be attempting to backcalculate too many unknown layer moduli (i.e., greater than 3 or 4).

By necessity, one should expect to combine all bituminous layers (seal coats, asphalt concrete, etc.) into "one" layer unless there is evidence (or the potential) for distress, such as stripping, in an AC layer or some other such distress which is critical to pavement performance.

2.2.2 UNSTABILIZED BASE/SUBBASE COURSE

"Thin" base course beneath "thick" surfacing layers (say AC or PCC) often result in low base moduli. There are a number of reasons why this can occur. One, a thin base is not a "significant" layer under a very stiff, thick layer. Second, the base modulus may be relatively "low" due to the stress sensitivity of granular materials. The use of a stiff layer generally improves the modulus estimate for base/subbase layers.

2.2.3 SUBGRADE

If unusually high subgrade moduli are calculated, check to see if a stiff layer is present. Stiff layers, if unaccounted for in the backcalculation process, will generally result in unrealistically high subgrade moduli. This is particularly true if a stiff layer is within a depth of about 6 to 9 m (20 to 30 feet) below the pavement surface.

2.2.4 STIFF LAYER

Often, stiff layers are given "fixed" stiffness ranging from 700 to 7000 MPa (100,000 to 1,000,000 psi) with semi-infinite depth. This, in effect, makes the "subgrade" a layer with a "fixed" depth (instead of the normally assumed infinite depth). Currently, it appears advisable to use backcalculation software which uses an algorithm such as described and illustrated in Volume 2, SECTION 7.0, Paragraph 3.3.4, "Depth to Stiff Layer." What is not so clear is whether one should always fix the depth to stiff layer at say 6, 9, or possibly 15 m (20, 30, or 50 ft) if no stiff layer is otherwise indicated (i.e., use a semi-infinite depth for the subgrade). The depth to stiff layer should be verified whenever possible with other NDT data or borings.

The stiffness (modulus) of the stiff layer apparently can vary. If the stiff layer is due to saturated conditions (e.g. water table) then moduli of about 345 MPa (50,000 psi) appear more appropriate. If rock or stiff glacial tills are the source of the stiff layer then moduli of about 6 900 MPa (1,000,000 psi) appear to be more appropriate.

2.3 INITIAL MODULI AND MODULI RANGES

2.3.1 ASPHALT CONCRETE

2.3.1.1 Initial Moduli

There are several ways one can estimate the initial AC modulus (often referred to as "seed modulus"). One can use a modulus-temperature plot as illustrated in Volume 2, SECTION 7.0, Figure 7.5, if the AC temperature at the time of testing is known; however, data such as shown in Figure 7.5 are based on laboratory resilient moduli (load pulse = 100 msec).

2.3.1.2 Cracked AC Initial Moduli

Generally, fatigue cracked AC (less than 10 percent wheelpath hairline cracks) is often observed to have backcalculated moduli of about 700 to 1400 MPa (100,000 to 200,000 psi). What is most important in the backcalculation process, assuming surface fatigue cracking is present, is to determine whether the cracks are confined to only the immediate wearing course or go through the whole depth of the AC layer. For AC layers greater than 150 mm (6 inches) thick, cracking only in the wearing course is often observed on WSDOT pavements.

2.3.1.3 AC Moduli Ranges

If an AC modulus range is required, use your best estimate of the E_{ac}, then

$0.25\ E_{ac}$ to $5.00\ E_{ac}$

2.3.2 UNSTABILIZED BASES AND SUBBASES

Material Type	Initial Modulus MPa (ksi)	Moduli Range MPa (ksi)
Crushed Stone or Gravel Bases	240 (35)	70 to 7000 (10 to 150)
Crushed Stone or Gravel Subbases	210 (30)	70 to 700 (10 to 100)
Sand Bases	140 (20)	35 to 550 (5 to 80)
Sand Subbases	100 (15)	35 to 550 (5 to 80)

2.3.3 STABILIZED BASES AND SUBBASES

If unconfined compressive strength data is available:

Material Type	Unconfined Compressive Strength MPa (psi)	Initial Modulus MPa (ksi)	Moduli Range MPa (ksi)
Lime Stabilized	< 1.7 (< 250)	200 (30)	35 to 690 (5 to 100)
	1.7 to 3.4 (250 to 500)	340 (50)	100 to 1000 (15 to 150)
	> 3.4 (> 500)	480 (70)	140 to 1400 (20 to 200)
Cement Stabilized	< 5.2 (< 750)	2800 (400)	700 to 10000 (100 to 1500)
	5.2 to 8.6 (750 to 1250)	7000 (1000)	1400 to 20000 (200 to 3000)
	> 8.6 (> 1250)	10000 (1500)	2000 to 28000 (300 to 4000)

If not, assume unconfined compressive strength is 1.7 to 3.4 MPa (250 to 500 psi) for lime stabilized and 5.2 to 8.6 MPa (750 to 1250 psi) for cement stabilized and use corresponding moduli values.

2.3.4 SUBGRADE

Refer to Volume 2, SECTION 7.0, Table 7.9 for suggested typical values or Volume 2, SECTION 7.0, Paragraph 3.1.2 for equations to use in estimating E_{sg} (or M_R) from the deflection basin.

2.4 ASSUMED POISSON'S RATIOS

Material Type		Poisson's Ratio
Asphalt Concrete		0.35
Portland Cement Concrete		0.15 - 0.20
Base/Subbase	Stabilized	0.25 - 0.35
	Unstabilized	0.35
Subgrade Soils	Cohesive (fine grain)	0.45
	Cohesionless (coarse grain)	0.35 - 0.40
Stiff Layer		0.35 or less

2.5 CONVERGENCE ERRORS

2.5.1 ROOT MEAN SQUARE ERROR (RMS)

One should attempt to obtain matches between the calculated and measured deflection basins, in terms of RMS, of about 1 to 2 percent. Often, this cannot be achieved and suggests that the basic input data be checked (such as layer thicknesses). The Area value might help in this regard.

2.5.2 GENERAL

"High" convergence errors suggest that there exists some fundamental problem with a specific backcalculation effort. The problem could be with the deflection data, layer types, and thicknesses, or lack of material homogeneity which could include cracked and uncracked conditions. "High" convergence errors do not necessarily mean that the backcalculated layer moduli are "no good."

SECTION 4.0, APPENDIX 4.1

CASE STUDY PHOTOGRAPHS

Photo 1. MP 207.90, northbound lane, area of longitudinal and alligator cracking.

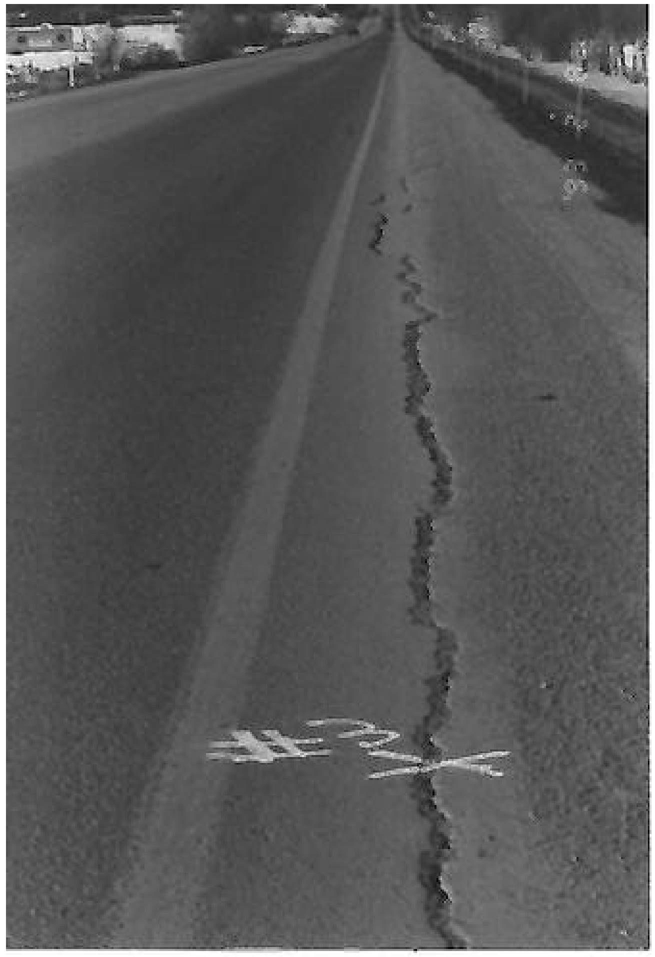

Photo 2. MP 208.00, northbound shoulder cracking, occurring from MP 207.82 to MP 208.29

Photo 3. MP 208.07, cracking within the northbound shoulder.

Photo 4. MP 208.18, northbound lane, longitudinal cracking progressing to alligator cracks.

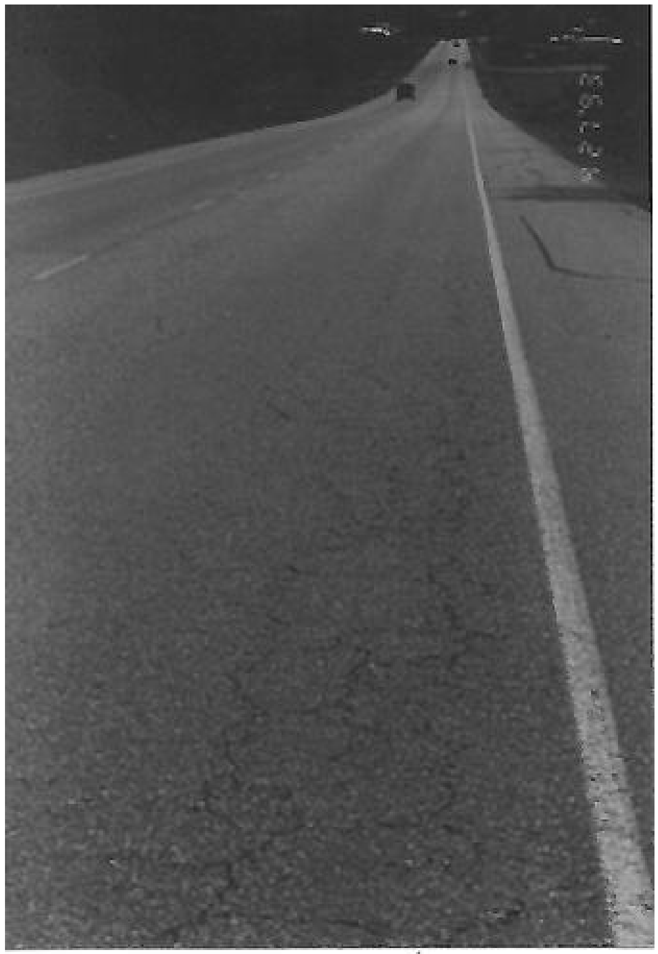

Photo 5. MP 208.56, northbound lane, typical alligator cracking within the wheel paths.

Photo 6. MP 208.56, southbound shoulder, shoulder roll off and cracking is typical from MP 208.52 to MP 208.56.

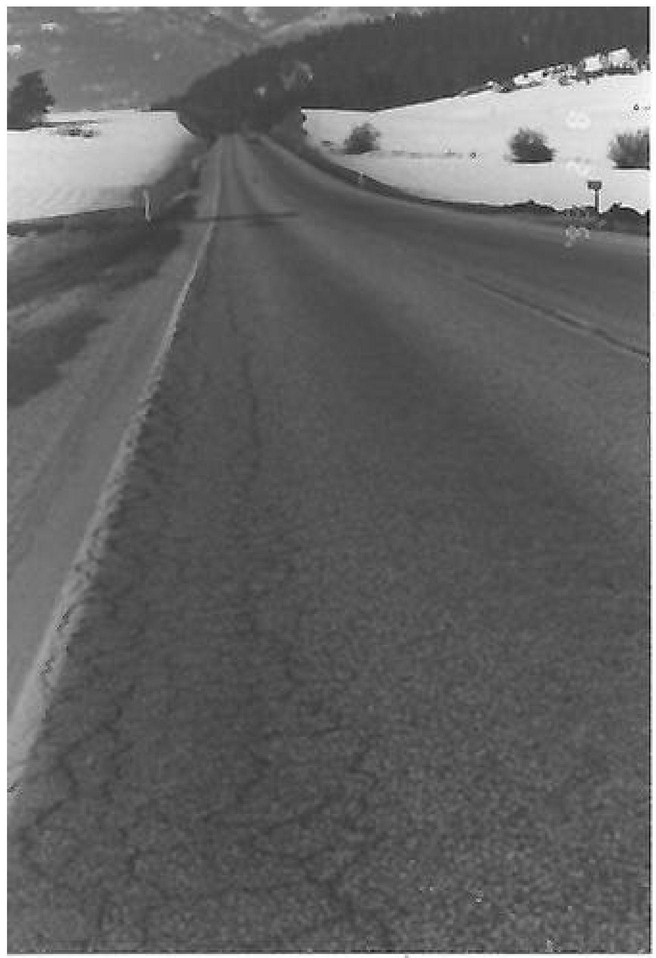

Photo 7. MP 209.00, southbound lane, looking north, alligator cracking within outside wheel path.

Photo 8. MP 209.00, southbound lane, looking south, alligator cracking within outside wheel path.

Photo 9. MP 209.05, southbound lane, frost heave causing 150 to 200 mm of differential movement.

Photo 10. MP 209.40, northbound lane, alligator cracking which occurs in both wheel paths.

Photo 11. MP 209.60, northbound lane, alligator and longitudinal cracking.

Photo 12. MP 209.82, northbound lane, frost heave that effects the northbound lane and shoulder.

Photo 13. MP 211.91, northbound lane, isolated distress occurring from MP 210.55 to MP 212.67.

Photo 14. MP 211.50, northbound lane, pavement is generally in good condition.

SECTION 5.0, APPENDIX 5.1

CASE STUDY PHOTOGRAPHS

Photo 1. MP 0.23 SB, full depth longitudinal crack at the core location (marked with an “X”).

Photo 2. MP 0.29 NB, beginning of curbed section through the town of Morton

Photo 3. MP 0.44 SB, transverse cracking at the core location (marked with an “X”).

Photo 4. MP 0.99 NB, core taken at full depth longitudinal crack. This section has numerous Maintenance patches.

Photo 5. MP 2.83 SB, pavement in relatively good condition, pavement rutting is present.

Photo 6. MP 3.68 NB, core taken at localized pavement distress.

Photo 7. MP 6.48 NB, highly distressed pavement, cross hatch indicates location of culvert.

Photo 8. MP 7.18 SB, pavement has several maintenance patches and rutting.

Photo 9. MP 9.96 SB, location of freeze/thaw damage which is typical of this section for several km. Damage could be caused by snowplows and heavy truck traffic.

Photo 10. MP 9.98 NB, location of wide longitudinal cracking. Damage may be caused by snowplows.

Photo 11. MP 15.08 NB, Maintenance has placed several AC or BST patches.